Water Circulation and Management of Infectious Salmon Anemia in the Salmon Aquaculture Industry of Southern Grand Manan Island, Bay of Fundy

F. H. Page, B. D. Chang, R. J. Losier, D. A. Greenberg, J. D. Chaffey and E. P. McCurdy

Science Branch, Maritimes Region
Fisheries and Oceans Canada
Biological Station
531 Brandy Cove Road, St. Andrews, NB
E5B 2L9

2005

Canadian Technical Report of Fisheries and Aquatic Sciences 2595

Fisheries and Oceans Canada | Pêches et Océans Canada

Canada

Canadian Technical Report of
Fisheries and Aquatic Sciences

Technical reports contain scientific and technical information that contributes to existing knowledge but which is not normally appropriate for primary literature. Technical reports are directed primarily toward a worldwide audience and have an international distribution. No restriction is placed on subject matter and the series reflects the broad interests and policies of the Department of Fisheries and Oceans, namely, fisheries and aquatic sciences.

Technical reports may be cited as full publications. The correct citation appears above the abstract of each report. Each report is abstracted in *Aquatic Sciences and Fisheries Abstracts* and indexed in the Department's annual index to scientific and technical publications.

Numbers 1-456 in this series were issued as Technical Reports of the Fisheries Research Board of Canada. Numbers 457-714 were issued as Department of the Environment, Fisheries and Marine Service, Research and Development Directorate Technical Reports. Numbers 715-924 were issued as Department of Fisheries and the Environment, Fisheries and Marine Service Technical Reports. The current series name was changed with report number 925.

Technical reports are produced regionally but are numbered nationally. Requests for individual reports will be filled by the issuing establishment listed on the front cover and title page. Out-of-stock reports will be supplied for a fee by commercial agents.

Rapport technique canadien des
sciences halieutiques et aquatiques

Les rapports techniques contiennent des renseignements scientifiques et techniques qui constituent une contribution aux connaissances actuelles, mais qui ne sont pas normalement appropriés pour la publication dans un journal scientifique. Les rapports techniques sont destinés essentiellement à un public international et ils sont distribués à cet échelon. Il n'y a aucune restriction quant au sujet; de fait, la série reflète la vaste gamme des intérêts et des politiques du ministère des Pêches et des Océans, c'est-à-dire les sciences halieutiques et aquatiques.

Les rapports techniques peuvent être cités comme des publications complètes. Le titre exact parait au-dessus du résumé de chaque rapport. Les rapports techniques sont résumé dans la revue *Résumés des sciences aquatiques et halieutiques*, et ils sont classés dans l'index annual des publications scientifiques et techniques du Ministère.

Les numéros 1 à 456 de cette série ont été publiés à titre de rapports techniques de l'Office des recherches sur les pêcheries du Canada. Les numéros 457 à 714 sont parus à titre de rapports techniques de la Direction générale de la recherche et du développe-ment, Service des pêches et de la mer, ministère de l'Environnement. Les numéros 715 à 924 ont été publiés à titre de rapports techniques du Service des pêches et de la mer, ministère des Pêches et de l'Environnement. Le nom actuel de la série a été établi lors de la parution du numéro 925.

Les rapports techniques sont produits à l'échelon régional, mais numérotés à l'échelon national. Les demandes de rapports seront satisfaites par l'établissement auteur dont le nom figure sur la couverture et la page du titre. Les rapports épuisés seront fournis contre rétribution par des agents commerciaux.

105-04865/

Canadian Technical Report of
Fisheries and Aquatic Sciences 2595

April 2005

Water circulation and management of infectious salmon anemia in the salmon aquaculture industry of southern Grand Manan Island, Bay of Fundy

by

F.H. Page[1], B.D. Chang[1], R.J. Losier[1], D.A. Greenberg[2], J.D. Chaffey[2], E.P. McCurdy[1]

[1] Fisheries and Oceans Canada, Biological Station,
531 Brandy Cove Road, St. Andrews, New Brunswick, Canada E5B 2L9

[2] Fisheries and Oceans Canada, Bedford Institute of Oceanography
1 Challenger Drive, Dartmouth, Nova Scotia, Canada B2Y 4A2

This is the two and sixty-first Technical Report of
the Biological Station, St. Andrews, New Brunswick

Errata: Page, F.H. et al. 2005. Water circulation and management of infectious salmon anemia in the salmon aquaculture industry of southern Grand Manan Island, Bay of Fundy. Can. Tech. Rep. Fish. Aquat. Sci. 2595.

Please note that there are errors in the citations for two of the references listed on page 24. The correct citations are as follows:

McGeachy, S.M. and Moore, M.J. 2003. Infectious salmon anemia in New Brunswick: an historical perspective and update on control and management practices (1997-2002). *In* International response to infectious salmon anemia: prevention, control, and eradication: proceedings of a symposium; 3-4 September 2002; New Orleans, LA. Technical Coordinators – O. Miller and R.C. Cipriano. Tech. Bull. 1902. Washington, DC: U.S. Dept. of Agriculture, Animal and Plant Health Inspection Service; U.S. Dept. of the Interior, U.S. Geological Survey; U.S. Dept. of Commerce, National Marine Fisheries Service. p. 145-153. (Available at: http://www.aphis.usda.gov/vs/aquaculture/isa-proceedings.pdf)

Murray, A.G. 2003. The epidemiology of infectious salmon anemia in Scotland. *In* International response to infectious salmon anemia: prevention, control, and eradication: proceedings of a symposium; 3-4 September 2002; New Orleans, LA. Technical Coordinators - O. Miller and R.C. Cipriano. Tech. Bull. 1902. Washington, DC: U.S. Dept. of Agriculture, Animal and Plant Health Inspection Service; U.S. Dept. of the Interior, U.S. Geological Survey; U.S. Dept. of Commerce, National Marine Fisheries Service. p. 55-62. (Available at: http://www.aphis.usda.gov/vs/aquaculture/isa-proceedings.pdf)

© Her Majesty the Queen in Right of Canada, 2005

Cat. No. Fs 97-6/2595E ISSN 0706-6457

Correct citation for this publication:

Page, F.H., Chang, B.D., Losier, R.J., Greenberg, D.A., Chaffey, J.D, and McCurdy, E.P. 2005. Water circulation and management of infectious salmon anemia in the salmon aquaculture industry of southern Grand Manan Island, Bay of Fundy. Can. Tech. Rep. Fish. Aquat. Sci. 2595 iii + 78 p.

ABSTRACT

Page, F.H., Chang, B.D., Losier, R.J., Greenberg, D.A., Chaffey, J.D, and McCurdy, E.P. 2005. Water circulation and management of infectious salmon anemia in the salmon aquaculture industry of southern Grand Manan Island, Bay of Fundy. Can. Tech. Rep. Fish. Aquat. Sci. 2595: iii + 78 p.

Successfully managing fish health issues associated with fish farming is an important aspect for the sustainability of aquaculture. Diseases such as infectious salmon anemia (ISA) are major issues facing the salmon aquaculture industry in many locations around the world. One mechanism that may facilitate the spread of the ISA virus between farms is the water-borne transport of viral particles. In an effort to help estimate the potential for water exchange of the ISA virus in the southwestern New Brunswick area of the Bay of Fundy, a three-dimensional tidal water circulation and particle transport model was developed for the southern area of Grand Manan Island. Water exchange scenarios based on the movement of particles from a fish farm during one tidal excursion, as predicted by the model, are compared to those estimated by a simple method assuming a 5-km radius circular zone of water exchange around each farm. The results can be used to estimate scenarios of viral transport and dispersal for use in fish health management, farm site selection and the designation of Bay Management Areas.

RÉSUMÉ

Page, F.H., Chang, B.D., Losier, R.J., Greenberg, D.A., Chaffey, J.D, and McCurdy, E.P. 2005. Water circulation and management of infectious salmon anemia in the salmon aquaculture industry of southern Grand Manan Island, Bay of Fundy. Can. Tech. Rep. Fish. Aquat. Sci. 2595: iii + 78 p.

La gestion fructueuse des problèmes de santé du poisson d'élevage est un aspect important de la durabilité de l'aquaculture. Certaines maladies, comme l'anémie infectieuse du saumon (AIS), posent de graves problèmes pour l'industrie de la salmoniculture dans de nombreux coins du monde. Le transport de virions par voie d'eau est un mécanisme qui peut faciliter la propagation du virus de l'AIS d'une ferme à une autre. En vue d'estimer le potentiel de transport de ce virus par voie d'eau dans le secteur sud-ouest de la baie de Fundy, au Nouveau-Brunswick, nous avons élaboré un modèle tridimensionnel de la circulation des eaux de marée et du transport des particules dans le secteur sud de l'île Grand Manan. Nous avons ensuite comparé les scénarios d'échange d'eau reposant sur le déplacement des particules issues d'une ferme durant une marée, tels que prédits par le modèle, aux scénarios estimés à l'aide d'une méthode simple, dans l'hypothèse d'une zone d'échange d'eau autour de chaque ferme d'un rayon de 5 km. Les résultats peuvent servir à évaluer des scénarios de transport et de dispersion de virus aux fins de gestion de la santé du poisson, du choix de site d'aquaculture et de désignation de zones de gestion de la baie.

INTRODUCTION

BACKGROUND

Infectious salmon anemia (ISA) first appeared among marine salmon farms in southwestern New Brunswick (SWNB) in the summer of 1996 and has been present every year since, resulting in considerable economic loss (McGeachy and Moore 2003). In response to the outbreak of this disease, several changes were made to the management of the industry. In 2000, the New Brunswick Department of Agriculture, Fisheries and Aquaculture (NBDAFA) introduced a new site allocation policy (NBDAFA 2000). One of the goals of this policy is to achieve single-year-class farming, since multiple-year-class farming is considered to be a major risk factor for the spread of ISA (McGeachy and Moore 2003). Implementation of single-year-class farming in SWNB requires the partitioning of the salmon farming area into Bay Management Areas (BMAs). The intent of BMAs is to improve cooperation and communication among farms, in order to assist in fish health and environmental management. The boundaries of the BMAs, when they were originally designated, were based on fish health, economic and oceanographic considerations (Halse 2002). Initially, oceanographic considerations were a relatively minor factor in defining BMAs, due in part to a lack of oceanographic knowledge. It was, however, recognized that the BMA boundaries might require adjustments based on new fish health, oceanographic and environmental knowledge.

In 2000, when the new site allocation policy was introduced, there were seven salmon farms operating in the southern Grand Manan Island area of SWNB (Fig. 1), with a total allowable production of 1,790,000 fish (NBDAFA, personal communication). These farms were located within three BMAs: four farms in BMA 20 (Seal Cove area), one farm in BMA 21 (Long Pond Bay area), and three farms in BMA 19 (White Head Island area). The farm in BMA 21 was an even year-class site (smolts are placed in sea cages in the spring of even years), while the other six farms were all odd year-class sites (smolts are placed in the spring of odd years).

In early 2001, NBDAFA authorized five new odd year-class salmon farms in the southern Grand Manan Island area (Fig. 1): one in BMA 20, three in BMA 21, and one in BMA 19. As a result of these five new farms, as well as production increases at some of the existing farms, the total allowable production level in these three BMAs more than doubled, to 3,689,000 fish (NBDAFA, personal communication). Eleven of these farms are odd year-class sites, while the pre-2001 farm in BMA 21 continues as the sole even year-class farm in the area. This means that BMA 21 now includes both even and odd year-class farms. The farms in the southern Grand Manan Island area are located quite close together: the minimum distance between each farm and its nearest neighbor (measured as the shortest distance via water between site boundaries) ranges from 0.3-2.0 km (average 0.9 km). In this report, we include all five new farms when we refer to the situation since 2001, even though one of the new farms (416) did not start operating in that year.

Authorization of the new farms in 2001 raised concerns regarding the risks to fish health due to potential interactions between the one even year-class farm (303) in BMA 21 and the new odd year-class farms in that BMA (farms 403, 408 and 491). The authorization of the new farms also raised the more general question of whether the addition of the new farms would reduce the

effectiveness of the existing BMA boundaries as indicators of separation in circulation and water exchange patterns. Further questions have arisen as a result of proposals for additional new farms in this area. Another question was whether the predominantly odd year-class farms in the southern Grand Manan Island area exchanged water with the even year-class farms in the eastern Grand Manan Island area.

Preliminary field and model information suggested that the circulation and water transport patterns in the southern Grand Manan Island area were spatially complex and that water was probably exchanged between several of the farms, and perhaps between BMAs. Existing knowledge was not sufficient to provide details, so in 2001 we began a project to help fill the knowledge gaps and give better estimates of the water exchange pathways between farms and BMAs (Page and Chang 2002; Page et al. 2004a). The project objectives were to develop specific advice for the southern Grand Manan Island area and to gain some general knowledge about the merits of different approaches for estimating the exchange of water between farms and areas. The project consisted of field observations (current meter moorings, conductivity-temperature-density transects, and drifter releases), development of a three-dimensional tidal circulation and particle transport model, and interpretation of circulation and transport results in the context of fish health management strategies. Only the oceanographic modelling aspects are included in this report. Some preliminary results have been previously reported (Page et al. 2004b). The present report includes the results of revised and additional analyses.

CAUSES OF THE SPREAD OF ISA AMONG SALMON FARMS

Epidemiological studies in Norway indicate that the ISA virus is likely transmitted via infected salmon, fish wastes, and/or processing effluents, and that seawater is a major route for disease transmission (Vågsholm et al. 1994; Jarp and Karlsen 1997). These studies found that the proximity of a farm to other ISA-infected farms and to salmon processing plants, especially where the separation distance was less than about 5 km, was among the greatest risk factors for the spread of ISA.

Various laboratory studies have shown that the virus can survive in seawater, but it is not clear how long it survives and remains infectious. Totland et al. (1996) found that the ISA virus can spread via seawater from infected Atlantic salmon, although the survival times of the virus in seawater were not determined. Nylund et al. (1994) found that the ISA virus could still be infectious in seawater after 20 h at 6°C. Torgersen (1998) reported that the virus survived in seawater for more than 48 h at 10°C, but that infectiousness was reduced after 24-48 h.

The study by Nylund et al. (1994) suggested that passive transmission of the virus via seawater could occur, but may be less important than transmission via agents such as sea lice. A Scottish study showed that boat traffic related to the transport of live fish and harvesting was linked to the spread of ISA over large distances (Murray et al. 2002).

A study in SWNB found that ISA virus prevalence was much higher within farms where ISA outbreaks were occurring (both in outbreak cages and in apparently healthy cages), than in healthy neighboring and distant farms (McClure et al. 2004).

These observations suggest that, at the larger scale (in the order of tens of kilometres or more), the spread of the disease is likely related to vectors such as boat traffic and the transport of fish among farms. However, at the smaller tidal excursion scale, physical transport of the ISA virus (from infected fish and discharged fish wastes) in the sea is a possible mechanism for disease spread (Murray et al. 2002). Such passive transport would be in the order of several kilometres or less, limited by the tidal exchange around farms (JGIWG 2000; Murray 2003). The pattern of occurrence of ISA in SWNB (McGeachy and Moore 2003; McClure et al. 2004) suggests that both large-scale vectors (such as movement of boats, fish, personnel, and equipment among farms) and smaller-scale passive transport via seawater among cages within a farm, and among adjacent farms, may have occurred.

THE USE OF MANAGEMENT AREAS OR ZONES IN SALMON FARMING

Geographically defined control, surveillance, and management areas or zones have been suggested and are being implemented in other salmon farming areas as a way to reduce the spread of ISA among salmon farms (Stewart 1998). The Norwegian Animal Health Authority's (2002) "Contingency plan for the control of infectious salmon anaemia in Norway" includes the establishment of Control Zones around ISA-infected farms. The Control Zone is a circular area with a radius of at least one tidal excursion (where known), but not less than 5 km, centred on the infected farm. Conditions applied to all farms within the Control Zone include: increased fish health surveillance; a prohibition of fish movement into or out of the zone; restrictions on the transport of fish through the zone; and a requirement for fallowing (6 mo for farms with confirmed ISA, 3 mo for suspect farms, and 2 mo for other farms) and disinfection of all farms prior to restocking. In addition, there is a larger area where increased surveillance will be applied. This Surveillance Zone includes all farms whose tidal excursions overlap with that of the infected farm (or an equivalent area based on hydrographic and epidemiological information) and should extend to a radius of 10-20 km from the infected farm.

Hydrographically defined Management Areas have also been proposed for the Scottish salmon farming industry (JGIWG 2000). A circle with a radius equal to one tidal excursion is drawn around the centre of each farm. In the absence of onsite water current data or computer modelling studies, the tidal excursions were estimated from maps of maximum tidal current speeds during spring tides in Scottish coastal waters. Most Scottish salmon farms are located in relatively sheltered sites where the maximum tidal amplitudes are restricted to 1 knot (0.5 $m \cdot s^{-1}$), which translates into an estimated tidal excursion of 7.3 km. A Management Area consists of all salmon farms having overlapping tidal excursion areas, although in a few cases slight overlaps in tidal excursions are allowed between adjacent Management Areas. When a Scottish farm becomes infected, it must be fallowed for at least 6 mo and all farms within its tidal excursion area must be simultaneously fallowed for at least 3 mo. Within the Management Area containing the infected farm, there are requirements for increased surveillance, as well as at least 6 wk fallowing of all farms. There is also a larger area of increased surveillance, within a circle with radius 40 km around the infected farm.

As mentioned above, BMAs have been established in SWNB, but since oceanography was only one of the factors used to define these areas, and the oceanographic data available at the time was

limited, there is some question as to whether they are effective for the control of ISA. Accordingly, this project examined the application of oceanographically based management areas as a way of controlling the spread of ISA in the southern Grand Manan Island area. The area of oceanographic influence around each farm was estimated by two methods: a simple method, in which the area was estimated as a circle with radius of 5 km around the farm, and a more complex method, which involved the development and use of a water circulation model to estimate the tidal excursion area. For the simple method, a 5-km radius was chosen based on the results of epidemiological studies and management practices in Norway, and some general knowledge of the tidal currents in southwestern New Brunswick.

We then looked at the influence of each farm on other farms in the area (i.e. the overlap of each farm's water exchange area, as estimated by both methods, with other farm sites), the influence of other farms on each farm (i.e. the overlap of other farms' water exchange areas on each farm site), and the interactions between water exchange areas of different farms (i.e. the overlaps among water exchange areas).

METHODS

The site boundaries for fish farms in the southern Grand Manan Island area were provided by NBDAFA and were entered into a Geographic Information System (MapInfo Professional® 7.0). Simple estimates of the zone of influence or water exchange around each farm were made by drawing a 5-km radius circle centred on the farm site, then deleting any land areas which fell within this circle, as well as any water areas which were separated from the farm site by land. If it was known that the fish cages were not located at the middle of a site, the circle was centred over the approximate location of the fish cage cluster. These circular areas were drawn using the MapInfo buffer tool, and are henceforth referred to as buffer zones.

More precise estimates of the tidal excursions around farms were made through the development of a three-dimensional tidal circulation and particle tracking model (Greenberg et al. 2005). The geographic domain of the model includes the entire Bay of Fundy and Gulf of Maine. The model estimates the tidal currents by dividing the geographic area into triangles (called finite elements) and by numerically solving the equations of motion at each x,y,z grid point within the model domain. When the model is run, a depth profile of the current is calculated at each corner of every triangle every 2.07 s. The circulation model is fully non-linear, has 21 sigma depth levels (reduced in water shallower than 10 m), and has variable horizontal resolution (minimum approximately 50 m). This feature of the finite-element model makes it well suited for covering the wide domain of influence, with the required detail in the area of interest needed to resolve local characteristics. The spatial resolution of the model is relatively coarse in the middle of the Gulf of Maine and quite fine in the southern Grand Manan Island area (Fig. 2). The model also has the capability of simulating wetting and drying of intertidal areas. Although the generic model code has the capability of including boundary forcing, internal water density and surface winds as current driving forces, the customized model for the Grand Manan Island area has only been run using boundary forcing by the principal diurnal lunar tide, the M_2 tide. Model-predicted currents at four stages of the tidal cycle are shown in Fig. 3. In general, water currents in the southern Grand Manan Island area move north and/or east with the flooding tide and south and/or west with the ebbing tide. The amplitude and phase of the M_2 model currents were

calibrated and compared to the amplitude and phase of the M_2 tide estimated from over ten current meter moorings deployed in the southern Grand Manan Island area (Page et al. 2004a).

Using the model, pseudo-drogues or numerical particles were released simultaneously from 36 points in a 200 m × 200 m square grid (40 m between adjacent grid points) centred approximately at the middle of the site or, if known, at the approximate centre of the fish cage cluster (Fig. 4). The particles were released and maintained at 1 m below the surface. At each farm, particles were released from the 36 grid points at hourly intervals over a 12-h period (for a total of 432 particle releases per farm), in order to represent conditions over one entire tidal cycle. For all sites, release 3 was started at the highest tide level (relative to the other hourly releases) and release 9 was started at the lowest tide level. Each particle was tracked over one tidal cycle (12.42 h) and its position was output at 20-min intervals. Some particle tracks were shorter than one tidal cycle, because the tracks terminated when they hit the shore. We used one tidal cycle duration because this duration has been used in ISA management plans in Norway and Scotland (Norwegian Animal Health Authority 2002; JGIWG 2000).

In order to estimate the areal extent of one model-derived tidal excursion, the marine surface area in the vicinity of the farm was divided into a grid of 100 m × 100 m square cells. A farm's tidal excursion area was then estimated as the total of all grid cells through which passed at least one of the 432 particle tracks from that farm. We also calculated and mapped the relative density of particle tracks among the grid cells. The density units were the number of particles (out of 432) that passed through a grid cell during the 12.42-h period of the tidal cycle, for all hourly releases (n=12) combined. When an individual particle passed through a given cell more than once, this was still counted as a single particle track. The density does not distinguish between the temporal sequences in which the particles passed through the cell. For example, a specific density value could represent the situation in which all of the particles were in a cell at the same time or all of the particles passed through the cell at different times. The density is an index of the intensity of exposure to a virus under the assumptions that the virus infectiousness is independent of time over the 12.42-h period and independent of the temporal sequence of the exposure history. It is an index of the cumulative exposure over the tidal cycle period. The density scale on each plot ranges over an order of magnitude with the darkest shade indicating an exposure density that is an order of magnitude (10 times) greater than the lightest shade.

We calculated and plotted the linear (straight line) distance traveled by each model particle from the release site as a function of time since release, in order to provide a comparison of the particle tracking model results to the 5-km radius approach. The time axis extends from 0 to 24 h and shows the relative release time of each particle group. The duration of the trajectory of any particle did not exceed 12.42 h.

To measure the influence (due to water circulation) each farm had on other farms, we determined which farm sites (receiving farms) were overlapped (at least partially) by each originating farm's water exchange area (as estimated by a 5-km radius buffer zone and by a model-derived tidal excursion area). To measure the influence (due to water circulation) that other farms had on each farm, we determined which water exchange areas (from originating farms) overlapped (at least partially) each receiving farm site. We also noted instances where the water exchange areas approached close to farm sites, without actually overlapping the sites. We defined "close" as

within 0.3 km of the site boundaries (this is the same as the recommended minimum separation distance between farm sites in New Brunswick; NBDAFA 2000).

As previously noted, the proposed Scottish Management Areas would include all farms with overlapping tidal excursion areas. To see how this type of Management Area would be applied in the southern Grand Manan Island area, we determined which farms had overlapping water exchange areas (estimated using 5-km radius buffer zones and model-derived tidal excursion areas).

We compared the interactions among farms using three measures of overlap. The simplest measure was the presence or absence of overlaps of each farm's water exchange area with the site boundaries and water exchange areas of all receiving farms (including the originating farm). More quantitative measures of overlap estimated the intensity of these overlaps. One quantitative measure was the areal extent of overlaps, measured as the proportion of the originating farm's water exchange area which overlapped other areas. Because the areas of the farm sites did not vary widely and were much smaller than the water exchange areas, the area proportion calculations for overlaps of a water exchange area with farm sites would produce relatively similar (and very small) values for all farms which were entirely overlapped, thus not providing an indication of the relative intensity of these overlaps. However, area proportion overlaps among water exchange areas (estimated as 5-km radius buffer zones or model-derived tidal excursion areas) would provide a measure of the intensity of overlap among these areas. Another quantitative measure of overlap, which could only be used with the model-derived tidal excursions, was to count the number of particle tracks (of the total 432 particles released from most farms) which overlapped the site boundaries and tidal excursion areas of receiving farms. For each measure, we compared the similarity among farms by performing cluster analyses on Bray-Curtis similarity coefficients using PRIMER 5 software (Clarke and Warwick 1994).

Both the buffer zones and model-derived tidal excursion areas were used to compare the amount of water exchange between farms operating in 2000 with that occurring following the addition of the five new farms licensed in 2001, especially the situation regarding the one even year-class farm (site 303) in BMA 21. We also looked at the amount of water exchange between farms in the southern Grand Manan Island area (predominantly odd year-class) and those in the eastern Grand Manan area (all even year-class). In addition, we investigated the potential consequences of moving the farm at site 303 to a site further east in Long Pond Bay and the potential consequences of adding new farms in Cow Passage (just north of White Head Island, along the border between BMAs 18 and 19).

RESULTS

ESTIMATION OF POTENTIAL INTERACTIONS AMONG FARMS USING 5-KM RADIUS CIRCULAR BUFFER ZONES

Figure 5 shows the 5-km radius circular buffer zones for farms operating in the southern Grand Manan Island area in 2000. The areas of the buffer zones ranged from 32.0-70.3 km^2 (Table 1). The farm sites and buffer zones which were overlapped by each farm's buffer zone in 2000 are shown in Tables 2 and 3. In all instances, where one farm's buffer zone overlapped a second

farm's site, the second farm's buffer zone overlapped the first farm's site. This is because all buffer zones had the same dimensions (5-km radius circles).

The buffer zone method indicates close oceanographic connections among all three BMAs in 2000, especially between BMAs 20 and 21. Each farm buffer zone overlapped an average of 4.1 farm sites (including the originating site) in 2000 (Fig. 6a, Table 4). The buffer zones of all farms in BMAs 20 and 21 overlapped all farm sites in these two BMAs, but with none of the farm sites in BMA 19, although the buffer zone of site 303 (in BMA 21) approached to within 0.3 km of site 316 (in BMA 19). The buffer zones of the two farms in BMA 19 overlapped each other's site, but did not overlap any farm site outside this BMA, although the buffer zone of farm 316 approached to within 0.3 km of site 303. The buffer zones of all seven farms overlapped the buffer zones of all other farms in 2000 (Fig. 6b, Table 4).

The cluster analysis based on the presence-absence of overlaps of buffer zones with farm sites in 2000 (Fig. 7a) showed two distinct clusters (0% similarity): one cluster of the two farms in BMA 19 (316 and 381) and one cluster of all other farms. For overlaps of buffer zones in 2000 (Fig. 7b), there was 100% similarity among all farms. The cluster analysis based on the areal extent of overlaps among buffer zones in 2000 (Fig. 8, Table 6) showed no separate clusters at 0-28% similarity; at 29% similarity the two farms in BMA 19 could be separated from the rest.

Figure 9 shows the 5-km radius circular buffer zones for all licensed farms in 2001. The areas of the buffer zones ranged from 32.0-71.7 km^2, with a mean of 57.0 km^2 (Table 1). The farm sites and buffer zones which were overlapped by each farm's buffer zone in 2001 are shown in Tables 2 and 3. As in 2000, where one farm's buffer zone overlapped a second farm's site, the second farm's buffer zone overlapped the first farm's site.

Each farm buffer zone overlapped an average of 7.2 farm sites (including the originating site) in 2001 (Fig. 10a, Table 4). The buffer zones of all farms in BMA 20, with the exception of new site 413, overlapped all farms in BMAs 20 and 21. The buffer zone of farm 413 overlapped all farm sites in BMA 20, plus one farm site in BMA 21 (site 491) and also approached to within 0.3 km of one other farm site in BMA 21 (site 408). The buffer zone of farm 303 (in BMA 21) overlapped all farm sites in BMA 21, all farm sites in BMA 20, except for site 413 and no farm sites in BMA 19, although it approached to within 0.3 km of site 316. The buffer zone of farm 403 (in BMA 21) overlapped all farm sites in BMA 21, all farm sites in BMA 20, except for site 413, and one farm site BMA 19 (site 316). The buffer zone of farm 408 (in BMA 21) overlapped all farm sites in BMA 21, all farm sites in BMA 20, except for site 413 (but approached within 0.3 km of that site) and no farm sites in BMA 19 (although it approached within 0.3 km of site 316). The buffer zone of farm 491 (in BMA 21) overlapped all farm sites in BMAs 21 and 20 and no farm sites in BMA 19. The buffer zone of farm 316 (in BMA 19) overlapped all farm sites in BMA 19, site 403 in BMA 21 (and also approached within 0.3 km of sites 303 and 408 in that BMA) and no farm sites in BMA 20. The buffer zones of the other two farms in BMA 19 (sites 381 and 416) overlapped all farm sites in BMA 19, but no farm sites in the other BMAs.

Each farm buffer zone overlapped an average of 10.7 buffer zones (including the originating farm's buffer zone) in 2001 (Fig. 10b, Table 4). The buffer zones of farms in BMA 20, except that of site 413, overlapped the buffer zones of all farms in BMAs 20 and 21 and two farms in

BMA 19 (316 and 381). The buffer zone of farm 413 overlapped the buffer zones of all farms in BMAs 20 and 21, but none from BMA 19. The buffer zones of all farms in BMA 21, except that of farm 491, overlapped buffer zones of all farms in the southern Grand Manan area. The buffer zone of farm 491 overlapped the buffer zones of all farms except that of farm 416 (in BMA 19). The buffer zones of farms 316 and 381 (in BMA 19) overlapped the buffer zones of all farms in southern Grand Manan, except that of farm 413. The buffer zone of farm 416 (in BMA 19) overlapped the buffer zones of all three farms in BMA 19, plus those of farms 303, 403 and 408 in BMA 21, but none of the buffer zones of farms in BMA 20.

The cluster analysis, based on the presence-absence of overlaps of buffer zones with farm sites in 2001 (Fig. 11a), showed similar results to those for farms operating in 2000 (Fig. 7a), but with slightly lower similarity among farms; there was separation into two clusters (at 6% similarity): one cluster of the three farms in BMA 19 (316, 381, and 416) and one cluster of all other farms. For overlaps of farm buffer zones in 2001 (Fig. 11b), there was high (61%) similarity among all farms. The cluster analysis, based on the areal extent of overlaps of buffer zones of farms in 2001 (Fig. 12, Table 6), showed less similarity than the presence-absence estimates, but at 0-28% similarity there was still only one cluster for all farms; at 29% similarity, the three farms in BMA 19 could be separated from the rest.

DESCRIPTIONS OF MODEL-DERIVED TIDAL EXCURSIONS

Figure 13 shows the particle tracks for each of the hourly releases from each farm. The tracks were often complex, showing changes in direction influenced by the changing tides and topography. Figure 14 shows the individual tidal excursion areas (all hourly releases combined), as predicted by the model, for each farm in the southern Grand Manan Island area, including the relative density of particle tracks (for all hourly releases from a given farm combined) present in 100 m × 100 m grid cells. The model-derived tidal excursion areas were non-circular and were considerably smaller in area than the 5-km radius circular buffer zones for all farms, except farms 381 and 416 in BMA 19 (Table 1).

Figure 15 shows the average displacement of particles versus time (i.e. straight-line distance traveled from the release point, averaged for all 36 particles released at the same time) for each of the hourly releases from each farm. These figures show that there is a net movement away from the starting grid by the end of one tidal cycle. However, the direction of the particle tracks changes with the tide, so at times the particles may be moving back toward the farm site. The maximum displacement of model particles from each farm site (maximum straight-line distance from the release point, averaged for all particle tracks in each release) in one tidal excursion, ranged from 2.3-13.9 km (average for all farms = 6.1 km). The maximum displacements showed considerable variation among BMAs: for farms in BMA 20, the range was 2.3-4.0 km (average = 3.2 km); for farms in BMA 21, the range was 3.0-5.4 km (average = 4.2 km); and for farms in BMA 19, the range was 12.5-13.9 km (average = 13.3 km).

Farm 003 (BMA 20)

The tidal excursion area of farm 003 was relatively small (2.9 km^2), extending both south along the western shore of Wood Island as far as farm 270, and east around the northern tip of Wood

Island. The particle releases (Fig. 13a) followed two main trajectories. Particles from releases 0 and 1 initially moved away from the release site in a north-northeasterly direction parallel to the western shore of Wood Island, but soon reversed direction and moved south-southeasterly through the release site and almost to farm 270. They then reversed direction again, passing through the release site again, ending near the northern tip of Wood Island. Particles from releases 2 and 3 showed similar trajectories, except there was no initial movement to the north-northeast and release 2 touched farm site 270. Also, particles from both releases started to reverse again at the end of the tidal cycle (near the northern tip of Wood Island). Releases 4-6 initially moved in a south-southwesterly direction, then reversed direction (before reaching farm 270) and moved in a north-northeasterly direction through the release site, then east into Long Pond Bay (between farms 303 and 403), before reversing directions again and moving west back into Seal Cove. The movement of particles from the remaining five releases (releases 7-11) was similar to that of releases 4-6, but without the initial movement to the south-southwest and ending with movement in a south-southwesterly direction down the channel between Grand Manan and Wood Islands (west of the release site) and then (with the exception of release 7) another reversal back in a north-northeasterly direction toward Seal Cove.

Particles from one release (release 2) entered farm site 270 and those from two other releases (releases 1 and 3) approached within 0.3 km of that farm. Particles from eight releases (releases 4-11) entered into BMA 21, but did not approach within 0.3 km of any farms in that BMA. Hence, the particles from farm 003 have a potential influence on one other farm site in BMA 20 and may also provide a potential linkage between BMAs 20 and 21.

The cumulative density plot for farm 003 (Fig.14a) indicates the highest density of particle tracks (100+ particle passes per grid cell per tidal cycle) is in a path about 4 km in length that runs along a trajectory that is parallel to the western and northern shores of Wood Island, with the latter running through the channel between Seal Cove (BMA 20) and Long Pond Bay (BMA 21).

Six of the particle releases (releases 5-10) moved a maximum linear distance of 2-3 km away from the release site (Fig. 15a). The other six releases moved a maximum linear distance of only 1-2 km.

Farm 202 (BMA 20)

The tidal excursion area of farm 202 was relatively small (2.2 km^2) and elongated, staying close to the shore of Grand Manan Island. The trajectories (Fig. 13b) of all 12 particle releases moved along a north-northeasterly to south-southwesterly axis. Six of the releases (releases 0-5) drifted south-southeast through farm 292 during some stage of their trajectory. The remaining six releases (releases 6-11) moved in a north-northeasterly direction away from the release site and remained in the northern Seal Cove area. One of these trajectories (release 7) barely entered Long Pond Bay (BMA 21) before reversing back into Seal Cove.

As noted above, particles from six releases (releases 0-5) passed through adjacent farm 292, but did not go near any other farms, while particles from two other releases (releases 6 and 11) approached within 0.3 km of farm 292. Particles from the other six releases did not go near any

farms (except the release site). Hence, this farm is relatively isolated: particles from farm 202 have a potential influence on only one other farm site.

The cumulative density plot for farm 202 (Fig.14a) reflects the narrow spread of the individual particle trajectories and shows the highest density of particle tracks (100+ particle passes per grid cell per tidal cycle) is in a north-northeast to south-southwest path that is 3.3 km in length. The high density zone passes through farm 292.

Three of the particle releases (releases 1-3) moved a maximum linear distance of 2.5-3.0 km away from the release site, six (releases 0, 4 and 7-9) moved 1-2 km away and the remaining three (releases 5, 10 and 11) moved less than 1 km away (Fig. 15a).

Farm 270 (BMA 20)

The tidal excursion area of farm 270 was 9.3 km^2 and extended both north along the western shore of Wood Island past farm 003, as well as south, then east, entering farms 491 and 408, and approaching to within 120 m of farm 403. Particles from release 0 (Fig. 13c) initially moved away from the release site in a north-northeasterly direction parallel to the western shore of Wood Island. When the tide turned, the particles moved in a south-southwesterly direction and retraced their earlier path back to the release site. They then continued in a southerly direction before veering toward the east (south of Wood Island) and ending at or near farms 491 and 408 (on either side of Outer Wood Island in BMA 21). Particles from releases 1-4 initially moved in a south-southwesterly direction (except particles from release 1 showed a brief initial movement to the north-northeast before reversing to the south-southwest), then turned east, proceeding south of Wood and Outer Wood Islands, then turned north, passing through or just east of farm 408, then approaching to within 0.5 km of farm 403 before reversing. Particles from release 5 initially moved south, where several paths were truncated upon hitting small islands. Some of the remaining particles proceeded east and entered the channel between Wood and Outer Wood Islands, passing through farm 491 before reversing, while other particles remained outside of the channel. Some of the particles from release 6 behaved like those particles from release 5 which had entered the channel between Wood and Outer Wood Islands, while others initially moved south, then after a short distance, they reversed direction, passing through the release site in a north-northeasterly direction along the shore of Wood Island, before reversing again (before reaching farm 003). Particles from the remaining five releases (releases 7-11) moved on the flooding tide in a north-northeasterly direction along the shore of Wood Island, passing through or near farm 003, then reversed, moving back toward the release site.

Particles from four releases (releases 7-10) passed through farm 003 (in BMA 20) and particles from one other (release 11) passed within 0.3 km of that farm. Particles from three releases (releases 0, 1 and 4) passed through farm 408 (in BMA 21) and particles from two other releases (releases two and 3) passed within 0.3 km of that farm. Particles from three releases (releases 1, 3 and 4) passed within 0.3 km of farm 403 (in BMA 21). Particles from three releases (releases 0, 5 and 6) passed through farm 491 (in BMA 21). Hence, the particles from farm 270 have a potential influence on four other farm sites and may provide a linkage between BMAs 20 and 21.

The cumulative density plot for farm 270 (Fig.14b) indicates that the highest density of particle tracks (100+ particle passes per grid cell per tidal cycle) is in a path that is about 3 km in length along a trajectory running mainly north-northeast of the release site. Farm 003 lies within 100 m of the high density path.

Five of the particle releases (releases 1-4 and 8) moved a maximum linear distance of 3-4 km away from the release site and another five (releases 0 and 7-10) moved 2-3 km away. The remaining two releases (releases 5 and 6) moved a maximum linear distance of only 1-2 km (Fig. 15b).

Farm 292 (BMA 20)

The tidal excursion area of farm 292 was similar in size and shape to that of nearby farm 202. The tidal excursion area was relatively small (3.3 km^2) and elongated, staying close to the shore of Grand Manan Island. The trajectories (Fig. 13d) of the 12 particle releases moved along a north-northeasterly to south-southwesterly axis. Particles from release 0 moved initially in a north-northeasterly direction, reaching farm 202 before reversing, passing through the release site and continuing in a south-southwesterly direction; they then reversed again (without reaching farms 413 or 270), returning to the release site. Releases 1-3 were similar to release 0, but without the initial northerly movement into farm 202. Releases 4-5 were similar to releases 1-3, but did not travel as far south and, at the end, the particles continued further north, reaching farm 202. Particles from releases 6-11 initially moved in a north-northeasterly direction through farm 202 into Seal Cove, before reversing, passing again through farm 202 and the release site.

Nine of the 12 releases (releases 0 and 4-11) had trajectories which entered adjacent farm site 202, but did not go near any other farms. Particles from the other three releases approached within 0.3 km of farm 202, but did not go near any other farms, except one particle from release 2 approached within 0.3 km of farm 270. Hence, farm 292 is relatively isolated: particles from this farm have a high potential to influence only one other farm site (202), plus a very low potential to influence one other farm site (270).

The cumulative density plot for farm 292 (Fig.14b) reflects the narrow spread of the individual particle trajectories and shows the highest density of particle tracks (100+ particle passes per grid cell per tidal cycle) is in a north-northeasterly to south-southwesterly path that is about 4 km in length and passes through farm 202.

Two of the particle releases (releases 2 and 3) moved a maximum linear distance of 3.0-3.3 km away from the release site, three (releases 0, 1 and 4) moved 2-3 km away, and the remaining seven moved a maximum linear distance of only 1-2 km (Fig. 15b).

Farm 413 (BMA 20)

The tidal excursion area of farm 413 was relatively small (4.0 km^2) and elongated, staying close to the shore of Grand Manan Island (except at its southern tip) and not overlapping with any other farm sites or farm tidal excursion areas. The particle releases (Fig. 13e) followed three main trajectories. The particles from five releases (releases 0-4) moved, on the ebbing tide, in a

southwesterly direction away from the release site, then when the tide turned the particles moved north back through the release site. The particles from another five releases (releases 6-10) moved with the flooding tide in a north-northeasterly direction, along the shore of Grand Manan Island, then when the tide turned, the particles reversed direction and returned to the release site. Particles from releases 5 and 11 showed trajectories that were intermediate between these two groups: the trajectories extended a little to the southwest and to the northeast of the release site.

None of the 12 releases had trajectories which passed through or near other salmon farms. Hence, site 413 appears to be isolated from all other farms.

The cumulative density plot for farm 413 (Fig.14c) indicates that the highest density of particle tracks (100+ particle passes per grid cell per tidal cycle) is in a path that is about 4 km in length, extending from the release site to the north-northeast and the south-southwest.

One of the particle releases (release 2) moved a maximum linear distance of 3.4 km away from the release site, seven (releases 0, 1, 3, 4 and 6-8) moved 2-3 km away, and the remaining four (releases 5 and 9-11) moved 1-2 km away (Fig. 15c).

Farm 303 (BMA 21)

The tidal excursion area of farm 303 was relatively small (5.3 km^2), extending mostly in the east-west direction and not overlapping with any other farm sites. The particle releases (Fig. 13f) followed two main trajectories. Particles from three of the releases (releases 1-3) initially moved west into Seal Cove, approaching to within about 0.5 km of farm 202 and/or farm 292; they then reversed direction, moving east back to the release site. Particles from releases 0 and 4 were similar to those of releases 1-3, except they did not move as far west into Seal Cove and they extended further east (east of the release site) at the end. Particles from releases 5-8 moved initially east, then reversed, moving back toward the release site. Particles from releases 9-11 were similar to those of releases 5-8, but did not move as far east initially and, at the end, before reaching the release site, they turned south-southeast.

None of the 12 releases had trajectories which passed within 0.3 km of any other farm sites. Five of the releases (releases 0-4) had trajectories which entered BMA 20, although the closest any particles came to farms in that BMA were a few particles from one release (release 2) which approached to within 0.4 km of farms 202 and 292. Hence, farm 303 appears to be relatively isolated from other farms, but may provide a potential linkage between BMAs 20 and 21.

The cumulative density plot for farm 303 (Fig.14c) indicates that the highest density of particle tracks (100+ particle passes per grid cell per tidal cycle) is in a path that is about 3 km in length, extending from the release site mainly to the west.

Seven of the particle releases (releases 1-3 and 5-8) moved a maximum linear distance of 2-3 km away from the release site and the remaining five (releases 0, 4 and 9-11) moved 1-2 km away (Fig. 15c).

Farm 403 (BMA 21)

The tidal excursion area of farm 403 was relatively large (21.9 km^2), extending both north-south, as well as east toward White Head Island. The trajectories (Fig. 13g) of particles from releases 0-4 moved initially south, through farm 408, then east and northeast toward White Head Island, approaching very close to farm 316. Particles from releases 5 and 6 also initially moved south through farm 408, then turned north-northeasterly, touching the eastern edges of farm 408 and the release site, then turning west, moving between farms 303 and 403. Particles from releases 7-9 initially moved northeast, then west, passing just south of farm 303 and just crossing the boundary into BMA 20. Particles from release 10 initially moved north-northeast a short distance, then turned west toward Wood Island; some particle tracks ended near the northeastern shore of Wood Island, while some headed south into farm 408, then turned north again back into the release site. Particles from release 11 initially moved north a short distance, then turned south, past the eastern tip of Outer Wood Island, then turned north again, passing through farm 408, ending in or near the release site.

Particles from nine of the 12 releases (releases 0-6 and 10-11) entered farm site 408. Particles from two releases (releases 7 and 8) approached within 0.3 km of farm 303. Particles from three releases (releases 2-4) approached within 0.3 km of farm 316 (in BMA 19). Hence, particles from farm 403 have a high potential influence on one other farm site within BMA 21 (site 408) and a lower potential influence on even year-class farm 303 in BMA 21 and farm 316 in BMA 19.

The cumulative density plot for farm 403 (Fig.14d) indicates that the highest density of particle tracks (100+ particle passes per grid cell per tidal cycle) is in a path that is about 2.7 km in length, extending from the release site mainly to the south-southwest.

Four of the particle releases (releases 1-4) moved a maximum linear distance of 4-5 km away from the release site, one (release 0) moved 3-4 km away, five (releases 5, 7-9 and 11) moved 2-3 km away and the remaining two (releases 6 and 10) moved 1-2 km away (Fig. 15d).

Farm 408 (BMA 21)

The tidal excursion area of farm 408 was similar to that of farm 403: it was relatively large (31.0 km^2), extending both north-south, as well as east toward White Head Island. The trajectories (Fig. 13h) of particles from release 0 initially moved north for a short distance, then turned southwesterly (passing through the release site), then easterly and northeasterly toward White Head Island. Particles from releases 1-4 had trajectories which were similar to those of release 0, but without the initial north movement. Particles from release 5 had similar trajectories, except they extended further south and west at the end of their trajectories. Particles from release 6 initially moved south, then north-northeast, passing just east of the release site and farm 403, then turned west between farms 303 and 403. Particles from releases 7 and 8 initially moved north, through farm 403, then west between farms 303 and 403, ending near the eastern shore of Wood Island. Particles from releases 9-11 initially moved north through farm 403, then reversed and headed south through the release site. Releases 10 and 11 then continued east and northeast.

Particles from five releases (releases 7-11) entered farm site 403 and particles from two other releases (releases 0 and 6) came within 0.3 km of that farm. Particles from one release (release 5) came within 0.3 km of farm 316 (in BMA 19). Hence, particles from farm 408 have a potential influence on one other farm site in BMA 21 (site 403) and, to a lesser extent, one farm site in BMA 19 (site 316). The potential for influence of particles from farm 408 on even year-class farm 303 appears to be low: just a few particles from one release (release 6) approached as close as 0.4 km to that farm.

The cumulative density plot for farm 408 (Fig.14d) indicates that the highest density of particle tracks (100+ particle passes per grid cell per tidal cycle) is in a path that is about 2 km in length, extending from the release site mainly to the south-southwest.

One of the particle releases (release 5) moved a maximum linear distance of 5.4 km away from the release site. Five others (releases 1-4 and 6) moved 4-5 km away, one (release 0) moved 3-4 km away and the remaining five (releases 7-11) moved 2-3 km away (Fig. 15d).

Farm 491 (BMA 21)

The tidal excursion area of farm 491 was somewhat smaller (8.6 km^2) than those of farms 403 and 408, extending both north then east in the channel between Wood and Outer Wood Islands, as well as south then east and north, overlapping farms 403 and 408. The particle releases (Fig. 13i) followed two main trajectories. Particles from releases 0 and 1 initially moved a short distance northeast within the channel between Wood and Outer Wood Islands, then reversed and moved back through the release site, then east (south of Outer Wood Island) then north-northeast, touching the southeastern corner of farm 408 and ending near farm 403. Particles from releases 2-4 showed similar trajectories to those of releases 0 and 1, but without the initial northeast movement and, at the end, they began to reverse again, moving in a southwestern direction into or near farm 403. Release 5 was also similar, but the trajectories remained closer to the south shore of Outer Wood Island and at the end, the trajectory continued south-southwesterly through farm 408 and past Outer Wood Island. Particles from releases 6-8 moved mostly east within the channel between Wood and Outer Wood Islands; most particles then reversed (before reaching farm 408), passing through the release site, but a few particles exited the eastern end of the channel and moved south close to the eastern shore of Outer Wood Island. Particles from releases 9-11 showed similar trajectories to the majority of those in releases 6-8: they all reversed upon reaching the eastern end of the channel, and moved back through the release site then south and east around Outer Wood Island, with releases 10 and 11 reaching or approaching farm 408.

Particles from six of the 12 releases (releases 0-2 and 4-5) entered farm site 408 and particles from the remaining five releases approached within 0.3 km of that farm. Particles from two releases (releases 4 and 5) entered farm site 403 and particles from another four releases (releases 0-3) approached within 0.3 km of that farm. Hence, particles from farm 491 have a potential influence on two other farm sites, both within BMA 21.

The cumulative density plot for farm 491 (Fig.14e) indicates that the highest density of particle tracks (100+ particle passes per grid cell per tidal cycle) is in a path that is about 1.7 km in length, extending from the release site to the northeast and southwest.

Four of the particle releases (release 1-4) moved a maximum linear distance of 3-4 km away from the release site, three (releases 0, 5 and 11) moved 2-3 km away and the remaining five (releases 6-10) moved 1-2 km away (Fig. 15e).

Farm 316 (BMA 19)

The tidal excursion area of farm 316 was large (49.0 km^2), extending mainly south and west from White Head Island. The particle releases (Fig. 13j) followed three main trajectories. Three of the releases (releases 0, 10-11) initially moved south-southeast, then moved west around the northern shore of Kent Island and then reversed. Particles from releases 1-4 initially moved west, then southeast and east (passing south of farms 381 and 416), then south-southwest away from White Head Island. Particles from releases 5-9 initially moved southeast, going through or close to farms 381 and 416, then turned south and southwest away from White Head Island.

No particles from any release entered farm site 381, but particles from 10 releases (releases 0, 1 and 4-11) approached within 0.3 km of that farm. Particles from four releases (releases 6-9) entered farm site 416, while particles from four other releases (releases 3-5 and 10) approached within 0.3 km of that farm. Hence, particles from farm 316 have a potential influence on the other two farm sites in BMA 19, but do not appear to have a potential influence any other farm sites.

The cumulative density plot for farm 316 (Fig.14e) indicates that the highest density of particle tracks (100+ particle passes per grid cell per tidal cycle) is within a 6-km arc extending east from the site around the south of White Head Island, touching both farms 381 and 416.

The maximum straight-line distance a release moved away from the release site was 10-14 km (releases 5-9). The other seven releases moved a maximum linear distance of 3-8 km away from the release site (Fig. 15e). These distances are mostly greater than the 5 km assumed in the circular buffer zone approach.

Farm 381 (BMA 19)

The tidal excursion area of farm 381 was large (81.6 km^2), extending mainly south and west from White Head Island. The trajectories (Fig. 13k) of releases 0 and 1 initially went southeast for a short distance, then reversed and moved northwest toward farm 316, then reversed again and moved southeast, passing just south of the release site and farm 416, and ending just east of White Head Island. The trajectories for particles from release 2 were similar to those of releases 0 and 1, but without the initial southeast movement. Particles from releases 3-6 initially moved south, then east (passing about 1-1.5 km south of White Head Island) and then turned southeast away from White Head Island. Particles from releases 7-10 moved in a similar manner to those from releases 3-6, except there was no initial south movement, so the east movement brought the particles in contact with farm 416, and at the end, the particle trajectories passed just south of

Kent Island. Particles from release 11 had similar trajectories to those from releases 7-10, except after heading east and contacting farm 416, the particles turned and moved in a more westerly direction, passing to the north of Kent Island.

None of the releases had particles which passed through farm 316, but three releases (releases 0-2) passed within 0.3 km of that farm. Particles from five releases (release 7-11) passed through farm 416 and particles from another four releases (releases 0-2 and 6) passed within 0.3 km of that farm. Hence, particles from farm 381 have a potential influence on the other two farm sites in BMA 19, but do not appear to have a potential influence any other farm sites.

The cumulative density plot for farm 381 (Fig.14f) shows that the highest density of particle tracks (100+ particle passes per grid cell per tidal cycle) is mostly within a small 1-km long path extending from the centre of the release site to the southeast, but is also found in some small areas within farm 416.

The maximum straight-line distance a release moved away from the release site was 11-13 km (releases 6-9). The other eight releases moved a maximum linear distance of 3-9 km away from the release site (Fig. 15f). These distances are mostly greater than the 5 km assumed in the circular buffer zone approach.

Farm 416 (BMA 19)

The tidal excursion area of farm 416 was large (96.2 km^2), extending mainly south and west from White Head Island. The trajectories (Fig. 13L) of releases 0-2 initially went west, passing just south of farms 381 and 316, then reversed, passing south of farms 316, 381 and 416, then turned south, just east of White Head Island. Particles from releases 3-7 initially moved southwest, then some particles moved in a mainly southerly direction (passing east of Kent Island), while others moved east and then southwest. Particles from releases 8-11 initially moved northeast along the east coast of White Head Island, then reversed and moved southwest, passing south of the release site and south of Kent Island.

No particles from any release entered into any other farm sites, but particles from two releases (releases 0 and 1) passed within 0.3 km of farm 316 and particles from one release (release 0) passed within 0.3 km of farm 381. Hence, farm 416 appears to be relatively isolated, with some potential influence on the other two farm sites in BMA 19, but no potential influence any other farm sites.

The cumulative density plot for farm 416 (Fig.14f) indicates that the highest density of particle tracks (100+ particle passes per grid cell per tidal cycle) is within a path about 3 km long, extending to the southwest and northeast of the release site, but not touching any other farms.

The maximum straight-line distance a release moved away from the release site was 10-14 km (releases 4-7 and 10-11). The other six releases moved a maximum linear distance of 4-8 km away from the release site (Fig. 15f). These distances are mostly greater than the 5 km assumed in the circular buffer zone approach.

ESTIMATION OF POTENTIAL INTERACTIONS AMONG FARMS IN THE SOUTHERN GRAND MANAN ISLAND AREA USING MODEL-DERIVED TIDAL EXCURSIONS

Figure 16 shows the model-derived tidal excursion areas for all seven farms operating in the southern Grand Manan Island area in 2000. The farm sites and tidal excursion areas which were overlapped by each farm's tidal excursion area in 2000 are shown in Tables 2 and 3. For all farms in 2000, where one farm's tidal excursion area overlapped a second farm's site, the second farm's tidal excursion area overlapped the first farm's site. Therefore, the numbers of farm sites overlapped by each farm's tidal excursion area (Fig. 17a) were identical to the numbers of farm tidal excursion areas which overlapped each farm site (Fig. 17b) and were also identical to the numbers of overlaps among tidal excursion areas (Fig. 17c).

The model-derived tidal excursion areas of farms in 2000 showed fewer overlaps (with farm sites and with tidal excursion areas) than the 5-km radius buffer zones (Table 4). BMAs 20 and 21 were still connected, although less than when using the circular buffer zones, but BMA 19 is separate. Each farm tidal excursion area overlapped on average of 1.9 farm sites (including the originating site) and an average of 1.9 tidal excursion areas (including the originating farm's tidal excursion area). Within BMA 20, there was apparent separation of the farms near the Grand Manan Island shore (farms 202 and 292) from the farms along the Wood Island shore (farms 3 and 270).

The cluster analysis based on the presence-absence of overlaps of each farm's tidal excursion area with farm sites in 2000 (Fig. 18a) showed four separate clusters (at 0% similarity): the two farms on the east side of BMA 20 (farms 3 and 270); the two farms on the west side of BMA 20 (farms 202 and 292); the one farm in BMA 21 (farm 303); and the two farms in BMA 19 (farms 316 and 381). The cluster analysis of overlaps among tidal excursion areas in 2000 (Fig. 18b) was identical to that for overlaps of tidal excursion areas with farm sites.

The cluster analysis calculated on the areal extent of overlaps among tidal excursion areas in 2000 (Table 6, Fig. 19) showed the same four clusters as in Fig. 18, but with less similarity of the farms within each cluster.

The cluster analysis based on the number of particle tracks which overlapped farm sites in 2000 (Table 7, Fig. 20a) showed the same four clusters as in Fig. 18 and 19, except that farms 316 and 381 in BMA 19 were completely separate from each other. Allowing 8% similarity, the two farms on the east side of BMA 20 (farms 3 and 270) could be put in a separate cluster. The cluster analysis based on the number of particle tracks overlapping tidal excursion areas in 2000 (Table 7, Fig. 20b) produced a similar pattern to that shown in Fig. 18a and 19.

Figure 21 shows the model-derived tidal excursion areas for all 12 licensed farms in 2001. The sites and tidal excursion areas which were overlapped by each site's tidal excursion area in 2001 are shown in Tables 2 and 3. Unlike in 2000, there were instances (6 out of the total 26 overlaps of farm sites by tidal excursion areas) where one farm's tidal excursion area overlapped a second farm's site, but the second farm's site tidal excursion area did not overlap the first farm's site. As a result, the numbers of farm sites overlapped by each farm's tidal excursion area (Fig. 22a) were

similar, but not identical, to the numbers of farm tidal excursion areas which overlapped each farm site (Fig. 22b, Table 5). The numbers of overlaps among tidal excursion areas (Fig. 22c) were higher than the numbers of overlaps between tidal excursion areas and farm sites.

As in 2000, the model-derived tidal excursion areas showed fewer overlaps (with farm sites and tidal excursion areas) than the 5-km radius buffer zones. On average, each farm's tidal excursion area overlapped 2.2 farm sites (including the originating site) and 4.8 tidal excursion areas (including the originating farm's tidal excursion area). The new farms added since 2001, especially those in BMA 21, increased the connectivity between BMAs 20 and 21 (due to water exchange between farm 270 in BMA 20 and new farms 408 and 491 in BMA 21), although, as in 2000, the number of overlaps was fewer than that predicted using the buffer zone method. BMA 19 was no longer as isolated as in 2000; however, none of the tidal excursions from farms in BMAs 20 and 21 overlapped farm sites in BMA 19 and none of the tidal excursions of farms in BMA 19 overlapped farm sites in BMA 20 or 21. New farm 413 (in BMA 20) was mostly isolated from all other farms, including those within its own BMA.

The cluster analysis based on the presence or absence of overlaps of tidal excursion areas with licensed farm sites in 2001 (Fig. 23a,b) showed five separate clusters (at 0% similarity): the one farm at the southwest end of BMA 20 (farm 413); the two other farms on the west side of BMA 20 (farms 292 and 202); the other two farms in BMA 20 (farms 270 and 003) together with the three new farms in BMA 21 (farms 403, 408 and 491); the original farm in BMA 21 (farm 303) by itself; and the three farms in BMA 19 (farms 316, 381 and 416). Allowing 30% similarity, the two eastern farms in BMA 20 (farms 003 and 270) could be separated from the three new farms in BMA 21 (farms 403, 408 and 491). For overlaps among tidal excursion areas in 2001 (Fig. 23c) there were only two separate clusters (at 0% similarity): farms 413, 292 and 202 from western BMA 20 in one cluster and all other farms in the other cluster.

The cluster analysis based on the areal extent of overlaps among tidal excursion areas of licensed farms in 2001 (Table 6, Fig. 24) showed a similar clustering pattern to that based on the presence or absence of overlaps among tidal excursion areas (Fig. 23c), except that the farms in western BMA 20 were separated into two clusters (with farm 413 separate from the other two farms) and, overall, the levels of similarity were lower.

The cluster analysis based on the number of particle tracks which overlapped licensed farm sites in 2001 (Table 7, Fig. 25a) showed a similar clustering pattern to that based on the presence or absence of overlaps (Fig. 23a), but with lower similarity values. For overlaps of particle tracks with tidal excursion areas of licensed farm sites in 2001 (Table 7 Fig. 25b), the clustering pattern was similar to that based on the areal extent of overlaps (Fig. 24).

One of the goals of this project was to examine the water exchange between the new odd year-class farms approved in 2001 in BMA 21 (farms 403, 408 and 491) and the existing even year-class farm 303 in the same BMA. If we use 5-km radius buffer zones to estimate the water exchange areas of these farms, we predict considerable interaction of the new farms with farm 303 (Tables 2 and 3, Fig. 26). Farm 303's buffer zone overlaps the other three farm sites and the buffer zones of each of the new farms overlap farm site 303. There is also considerable area overlap (Table 6) of the buffer zone of farm 303 with the buffer zones of the new sites (87%

area overlap with farm 403's buffer zone, 78% with farm 408's and 59% with farm 491's), as well as considerable area overlap of the new farms' buffer zones with that of farm 303 (64% of the area of farm 403's buffer zone, 51% of farm 408's and 43% of farm 491's).

Using model-derived tidal excursion areas to estimate water exchange, we see much less overlapping, compared to the overlapping of buffer zones (Tables 2 and 3, Fig. 26). This is due to the much smaller size of these areas and their non-circular shape. There is no overlapping of farm 303's tidal excursion area with any of the new farm sites and none of the new sites' tidal excursion areas overlap the site boundaries of farm 303, although the tidal excursion area of farm 403 comes close to site 303. The area overlaps of farm 303's tidal excursion area with the tidal excursion areas of the new farms (Table 6) are much less compared to the area overlaps of buffer zones (18% area overlap with farm 403's buffer zone, 12% with farm 408's and <1% with farm 491's) and the overlaps of the new farms' tidal excursion areas with that of farm 303 are less than 5% (4% of the area of farm 403's buffer zone, 2% of farm 408's and <1% of farm 491's).

As would be expected, the highest amount of overlapping (by area) among water exchange areas (using either method) is between farm 303 and the nearest of the new farms, site 403 (Fig. 26). Other measures of the intensity of overlap among model-derived tidal excursion areas also show that the overlapping is greatest between farms 303 and 403: 7 of 12 releases and 250 of 432 model particles from farm 303 enter farm 403's tidal excursion area, while 6 of 12 releases and 136 of 432 particles from farm 403 enter farm 303's tidal excursion area. For farm 408, the predicted water exchange is mostly going from farm 303 to this site, with very little in the reverse direction: 7 of 12 releases and 222 of 432 particles from farm 303 enter farm 403's tidal excursion area, while only 2 of 12 releases and 18 of 432 particles from farm 408 enter farm 303's tidal excursion area. For farm 491, the potential water exchange is predicted to be very small in both directions: no releases or particles from farm 303 enter farm 491's tidal excursion area and only 1 release and 2 particles from farm 491 enter farm 303's tidal excursion area.

ESTIMATION OF POTENTIAL INTERACTIONS BETWEEN FARMS IN THE SOUTHERN AND EASTERN AREAS OF GRAND MANAN ISLAND

Although the exchange of particles between BMA 18 and BMAs 19-21 were not the focus of this project, we also examined the tracks of particles released from farms in BMA 18. The buffer zones and model-derived tidal excursion areas indicated that there was little water movement from farms in the southern Grand Manan Island area to farms in the eastern Grand Manan Island area (Fig. 27). There was a partial overlap of farm 316's buffer zone with the southernmost farm in BMA 18 (farm 172), but none of the other buffer zones of farms in BMAs 19-21 overlapped any farms in BMA 18. None of the tidal excursion areas of farms in BMAs 19-21 overlapped any farm sites in BMA 18 (Fig. 27).

There appeared to be more water movement in the direction from farms in BMA 18 into the southern Grand Manan Island area, especially into BMA 19. There was only one overlap of a buffer zone from BMA 18 (that of farm 172) to a farm site (316) in BMA 19, but the tidal excursion areas of two farms in BMA 18 (farms 172 and 300) each overlapped two farm sites in BMA 19 (sites 316 and 381).

There were several overlaps of buffer zones of farms in BMAs 19-21 with buffer zones of all four farms in BMA 18 (Table 8). There were also overlaps of tidal excursion areas of five farms in BMAs 19 and 21 (all three farms in BMA 19, plus farms 403 and 408 in BMA 21) with those of two farms in BMA 18 (farms 172 and 300).

In conclusion, it appears that some farms in BMA 18 influence some farms in BMA 19, but farms in BMA 19 do not influence farms in BMA 18.

ESTIMATION OF POTENTIAL EFFECTS OF PROPOSED NEW FARM SITES IN THE SOUTHERN GRAND MANAN AREA

The buffer zones and model-derived tidal excursion areas predicted that moving the even year-class farm 303 approximately 2 km east (to a location designated as site 401, still within BMA 21) would increase the water exchange between farms in BMAs 21 and 19, while only slightly decreasing the exchange between farms in BMAs 21 and 20 (Fig. 28 and Table 9). The proposed site's buffer zone would overlap seven existing farm sites and the buffer zones of all 12 existing farms. The proposed site's tidal excursion area would overlap two other farm sites (farms 316 and 381 in BMA 19), as well as touching site 303 and approaching to within 150 m of farm 403. The tidal excursion area of site 401 would overlap the tidal excursion areas of eight farms, including those of all farms in BMA 21 (including farm site 303), one farm (003) in BMA 20 and all three farms in BMA 19.

The model-derived tidal excursions predicted that placing up to three new salmon farms in Cow Passage would have resulted in increased connectivity between farms in BMAs 19 and 18 (to the north, in the eastern Grand Manan Island area), as well as increasing the water exchange between BMAs 19 and 21 (Fig. 29 and Table 10). The buffer zones of these sites had overlaps with three existing farm sites in BMAs 19 (as well as with the buffer zones of these farms), as well as with buffer zones of three existing farms in BMA 21. The tidal excursion area of proposed site 402 (near the northern tip of White Head Island) was very small (1.27 km^2), staying close to the shore of White Head Island, and did not overlap any existing farm sites or their tidal excursion areas. The tidal excursion areas of the other two proposed farms (sites 418 and 419) were relatively large (23.2 and 26.3 km^2) and similar in shape, showing considerable overlap with each other, as would be expected considering the close proximity of these sites. Both of these sites' tidal excursion areas overlapped three existing farm sites (the three farms in BMA 19) and the tidal excursion areas of five existing farms (403 and 408 in BMA 21 and all three farms in BMA 19). The tidal excursion area of the northernmost of the proposed farms (419) also touched the boundaries of the southernmost farm in BMA 18 (farm 172).

DISCUSSION

The Norwegian ISA Control and Surveillance Zones and the Scottish Management Areas are based on the designation of zones of influence, based on one tidal exchange, around each farm (JGIWG 2000; Norwegian Animal Health Authority 2002). In the absence of detailed oceanographic information, these zones were considered to be circular in shape. The Norwegian Control Zones include all salmon farms inside the designated water exchange area of an infected

farm, while the Norwegian Surveillance Zones and Scottish Management Areas are based on overlaps among water exchange areas of adjacent farms.

The circular buffer zone approach may, on the one hand, underestimate the connectivity between sites if the choice of the buffer radius is too small. On the other hand, it overestimates the connectivity between sites, since actual exchange pathways are seldom circular. Our choice of a 5-km buffer radius was chosen on the basis of some preliminary information on the current speeds in the southern Grand Manan area and on the rationale used in Scotland and Norway (JGIWG 2000; Norwegian Animal Health Authority 2002). The particle trajectories estimated by our model suggest that this was a reasonable overall choice, although it underestimated the maximum distance travelled by most particles released from the three sites in BMA 19 and overestimated the maximum distance travelled by most particles released from sites in BMAs 20 and 21.

Salmon farms in southwestern New Brunswick are located quite close together, so the simple approach of using a 5-km radius circular zone of influence around each farm resulted in predictions of considerable overlap between zones and hence possible water exchange between farms within BMAs and between farms in different BMAs. When we drew 5-km buffer zones around salmon farms operating in the southern Grand Manan Island area in 2000, the overlaps with farm sites suggested two zones: one consisting of farms in BMAs 20 (Seal Cove area) and 21 (Long Pond Bay area) and the other of farms in BMA 19 (White Head Island area). When we looked at the overlaps among the buffer zones, this suggested one zone for all farms in the southern Grand Manan Island area. The new farms approved in 2001 did not result in substantial changes to the patterns of overlaps among zones.

The exchange pathways or particle trajectories, as indicated by the model results, are usually relatively narrow, curvilinear pathways. For BMAs 20 and 21, the model-predicted particle pathways covered considerably less area than the 5-km radius circular zones, while for two farms in BMA 19 the model-predicted tidal excursion areas were larger than the 5-km radius circular zones (Table 1). In addition, the model-derived particle pathways showed that the predicted overlaps usually occurred only during a portion of the tidal cycle.

The difference in the area covered by the particle trajectories resulted in the circular buffer zone approach overestimating the connectivity between sites by a factor of 3-4 times, as compared to the model results (compare Fig. 6 and 10 with Fig. 17 and 22). This factor may be reduced, but probably not eliminated, if the model results incorporated the effects of wind and other significant components of the tide on the circulation since these would increase the variation and geographic coverage of the estimated particle trajectories.

When instead of just looking at the presence or absence of overlaps, we refined our analysis to look at the intensity of overlap (i.e. looking at the area of overlap or the number of overlapping model particle tracks), we saw that the general pattern of overlapping among farms and zones did not change, but the amount of connectivity (as indicated by the similarity values in the cluster analyses) was generally less.

If we allowed no overlaps of tidal excursion areas with farm sites, the analyses would suggest two management areas for the southern Grand Manan area: farms 413, 292 and 202 in one group and all other farms in the other group. If a limited amount of overlapping water exchange is allowed, there is some justification for having four management areas: farm 413 alone; the western Seal Cove area (farms 292 and 202); the eastern Seal Cove area (farms 003 and 270) together with the Long Pond Bay area (existing BMA 21); and the White Head Island area (existing BMA 19). Preferably all of the farms in the southern Grand Manan Island area would be on the same year-class cycle, but the risk of maintaining farm 303 as an even year-class farm appears to be relatively low, since it is somewhat isolated (especially when the intensity of overlaps is considered) from its neighbors.

Since the 5-km radius buffer zone approach probably overestimates the number of connections between farm sites, and the tidal model probably underestimates the connections due to the omission of other components of the circulation, the real level of connectivity is probably somewhere between the two estimates. From a site planning perspective, it may be prudent to avoid increasing the connectivity between the farms, as would occur if additional sites were approved in the area, and it may be advantageous to work toward reducing the connectivity between closely linked farms. Alternatively, closely linked farms should be managed as if they were one farm.

The use of model-derived tidal excursions can be useful in predicting the impacts of moving farms or adding new farms on existing management areas. Using this method, we predict that the movement of farm 303 (in Long Pond Bay) east to site 401 would not have any benefits in terms of reducing water exchange among farms and would actually increase the water exchange between BMAs 19 and 21.

We also predict that placement of new farms in Cow Passage (just north of White Head Island) would increase the connectivity among the existing farms in BMA 19 and those along the eastern side of Grand Manan Island (BMA 18). At present, all farms along the eastern side of Grand Manan Island are even year-class sites, while all but one of the farms on the southern side are odd year-class sites. There is some water exchange between existing farms in the southern Grand Manan Island area with existing farms in the eastern Grand Manan Island area (mainly in the direction from the eastern farms to the southern farms, with very little exchange in the reverse direction). Addition of any new farms which would increase the water exchange between the eastern and southern farms should be avoided. Our results also suggest that if the two southernmost farms in BMA 18 were removed, there would be more separation (in terms of water exchange) between the eastern and southern finfish farming areas of Grand Manan Island.

The maps showing the spatial distribution of our index of exposure (the number of particles passing through a 100 m × 100 m grid cell during a single tidal cycle) illustrate the potential for the modelling approach to estimate a spatially dependant relative degree of exposure. This approach could also be used to estimate the cumulative risk of a particular farm to virus originating from more than one farm. However, it must be mentioned that fish health experts do not know enough about the infectiousness of the ISA virus to confidently translate the relative exposure index into a risk of infection. It should also be mentioned that the exposure index is based on the assumption that the circulation and particle trajectories are determined completely

by the M_2 tide. However, the approach can be customized with different time scales and different release and particle trajectory parameters (such as the depth of particle release, vertical movement behavior, the duration of particle infectiousness, the density of the release grid and the temporal sequence of release). Although the M_2 tide is the major component of the tide in this area, other factors do play a role and when they are included in the model the particle trajectories and exposure maps will be modified to some degree.

The approach we have used is viewed by fish health specialists, members of the salmon aquaculture industry, and regulators as being useful in helping to estimate interactions between farm sites and hence to estimate the potential for the spread of ISA. As a result, we are implementing this approach in other areas of southwestern New Brunswick. Ideally we would like to see such an approach implemented before aquaculture sites are approved, so that unwanted overlap scenarios could be avoided.

ACKNOWLEDGEMENTS

This project was funded in part by the Fisheries and Oceans Canada (DFO) Aquaculture Collaborative Research and Development Program, Heritage Salmon Ltd., and the New Brunswick Department of Agriculture, Fisheries and Aquaculture (NBDAFA). The work was conducted in collaboration with the New Brunswick Salmon Growers' Association (NBSGA), the salmon farms in the study area and the Southwestern New Brunswick Fish Health Technical Committee (FHTC). We thank the following individuals who participated in project meetings and/or provided other contributions to the project: S. Backman (Skretting, FHTC), M. Dowd (DFO), P. Fitzgerald (Heritage Salmon Inc.), N. Halse (NBSGA), L. Hammell (Atlantic Veterinary College, FHTC), B. Hill (NBDAFA), R. Lambert (Northeast Salmon Inc.), J. L'Aventure (Fundy Aquaculture Ltd.), D. MacPhee (Maritime Veterinary Services Ltd., FHTC), S. McGeachy (NBDAFA, FHTC), J. O'Halloran (Aquaculture Veterinary Services International, FHTC), G. Olivier (DFO, FHTC), W. Robertson (Heritage Salmon Inc.), D. Russell (Northeast Salmon Inc.), G. Smith (NBDAFA) and S. Smith (NBSGA).

REFERENCES

Clarke, K.R., and Warwick, R.M. 1994. Change in marine communities: an approach to statistical analysis and interpretation. Plymouth Marine Laboratory, Plymouth, UK. 144 p.

Greenberg, D.A., Shore, J.A., Page, F.H., and Dowd, M. 2005. A finite element circulation model for embayments with drying intertidal areas and its application to the Quoddy Region of the Bay of Fundy. Ocean Mod. 10: 211-231.

Halse, N. 2002. Rationale for the development of Bay Management Areas for the salmon farming industry in New Brunswick. *In* Fish Health and Oceanography Project of the Aquaculture Collaborative Research and Development Program: report of the initial meeting, 18 December 2001. Edited by F.H. Page and B.D. Chang. Can. Tech. Rep. Fish. Aquat. Sci. 2409: 13-14.

Jarp, J., and Karlsen, E. 1997. Infectious salmon anaemia (ISA) risk factors in sea-cultured Atlantic salmon *Salmo salar*. Dis. Aquat. Org. 28: 79-86.

McGeachy, S.M., and Moore, M.J. 2003. Infectious salmon anemia in New Brunswick: an historical perspective and update on control and management practices (1997-2002). *In* International response to infectious salmon anemia: prevention, control, and eradication: proceedings of a symposium; 3-4 September 2002; New Orleans, LA. Technical Coordinators - O. Miller and C. Rocco, C. Tech. Bull. 1902. Washington, DC: U.S. Dept. of Agriculture, Animal and Plant Health Inspection Service; U.S. Dept. of the Interior, U.S. Geological Survey; U.S. Dept. of Commerce, National Marine Fisheries Service. p. 145-153.

McClure, C.A., Hammell, K.L., Dohoo, I.R., Nerette, P., and Hawkins, L.J. 2004. Assessment of infectious salmon anaemia virus prevalence for different groups of farmed Atlantic salmon, *Salmo salar* L., in New Brunswick. J. Fish Dis. 27: 375-383.

Murray, A.G. 2003. The epidemiology of infectious salmon anemia in Scotland. *In* International response to infectious salmon anemia: prevention, control, and eradication: proceedings of a symposium; 3-4 September 2002; New Orleans, LA. Technical Coordinators - O. Miller and C. Rocco, C. Tech. Bull. 1902. Washington, DC: U.S. Dept. of Agriculture, Animal and Plant Health Inspection Service; U.S. Dept. of the Interior, U.S. Geological Survey; U.S. Dept. of Commerce, National Marine Fisheries Service. p. 55-62.

Murray, A.G., Smith, R.J., and Stagg, R.M. 2002. Shipping and the spread of infectious salmon anemia in Scottish aquaculture. Emerg. Infect. Dis. 8: 1-5.

NBDAFA (New Brunswick Department of Agriculture, Fisheries and Aquaculture). 2000. Bay of Fundy marine aquaculture site allocation policy. New Brunswick Department of Agriculture, Fisheries and Aquaculture, Fredericton, NB. 22 p.

Norwegian Animal Health Authority (Statens Dyrehelsetilsyn). 2002. Contingency plan for control of Infectious Salmon Anaemia (ISA) in Norway. Norwegian Animal Health Authority, Oslo, Norway. http://dyrehelsetilsynet.mattilsynet.no/dyrehelse/bekjempelsesplaner/bekjempelsesplan_ila/isa_contingency_plan/ (accessed March 7, 2005).

Nylund, A., Hovland, T., Hodneland, K., Nilsen, F., and Løvik, P. 1994. Mechanisms for transmission of infectious salmon anaemia (ISA). Dis. Aquat. Org. 19: 95-100.

Page, F.H., and Chang, B.D. (ed.). 2002. Fish Health and Oceanography Project of the Aquaculture Collaborative Research and Development Program: report of the initial meeting, 18 December 2001. Can. Tech. Rep. Fish. Aquat. Sci. 2409: vii + 47 p.

Page, F.H., Chang, B.D., and Greenberg, D.A. 2004a. Fish Health and Oceanography Project of the Aquaculture Collaborative Research and Development Program: final project report. Can. Tech. Rep. Fish. Aquat. Sci. 2543: vi + 47 p.

Page, F.H., Chang, B., Losier, R., Greenberg, D., and McCurdy, P. 2004b. Water circulation and management of ISA in the southwest New Brunswick salmon culture industry. Aquacult. Assoc. Can. Spec. Publ. 8: 64-68.

JGIWG (Joint Government/Industry Workshop Group on Infectious Salmon Anemia). 2000. Final Report of the Joint Government/ Industry Working Group on Infectious Salmon Anaemia (ISA) in Scotland. Scottish Executive, Fisheries Research Services, Marine Laboratory, Aberdeen, Scotland. 142 p.

Stewart, J.E. 1998. Sharing the waters: an evaluation of site fallowing, year class separation and distances between sites for fish health purposes on Atlantic salmon farms. Can. Tech. Rep. Fish. Aquat. Sci. 2218: vii + 56 p.

Torgersen, Y. 1998. Physical and chemical inactivation of the infectious salmon anaemia virus (ISA). *In* Workshop on Infectious Salmon Anaemia, St. Andrews, New Brunswick, 26 November 1997. New Brunswick Department of Fisheries and Aquaculture, Fredericton, NB. p. 44-53.

Totland, G.K., Hjeltnes, B.K., and Flood, P.R. 1996. Transmission of infectious salmon anaemia (ISA) through natural secretions and excretions from infected smolts of Atlantic salmon *Salmo salar* during their presymptomatic phase. Dis. Aquat. Org. 26: 25-31.

Vågsholm, I., Djupvik, H.O., Willumsen, F.V., Tveit, A.M., and Tangen, K. 1994. Infectious salmon anaemia (ISA) epidemiology in Norway. Prev. Vet. Med. 19: 277-290.

Table 1. Areas of water exchange areas of salmon farms in the southern Grand Manan area, estimated by two methods: 5-km radius circular buffer areas (excluding land or areas of water separated from the farm by land) and model-derived tidal exchange estimates (see text for details). Figures in bold italics are for new farms approved in 2001.

Bay Management Area (BMA) and farm site	Estimated area of water exchange (km^2)	
	5-km radius buffer zone	Model-derived tidal excursion area
BMA 20: Seal Cove area		
003	48.4	2.9
202	32.0	2.2
270	53.4	9.3
292	35.6	3.3
413	***59.0***	***4.0***
Mean ± SD in 2000 (n=4)	42.3 ± 8.8	4.4 ± 2.9
Mean ± SD in 2001 (n=5)	45.7 ± 10.3	4.3 ± 2.6
BMA 21: Long Pond Bay area		
303	46.8	5.3
403	***63.5***	***21.9***
408	***71.6***	***31.0***
491	***63.2***	***8.6***
Mean ± SD in 2000 (n=1)	46.8 ± 0.0	5.3 ± 0.0
Mean ± SD in 2001 (n=4)	61.3 ± 9.0	16.7 ± 10.3
BMA 19: White Head Island area		
316	68.2	49.0
381	70.3	81.6
416	***71.7***	***96.2***
Mean ± SD in 2000 (n=2)	69.2 ± 1.0	65.3 ± 16.3
Mean ± SD in 2001 (n=3)	70.1 ± 1.4	75.6 ± 19.7
All southern Grand Manan Island area		
Mean ± SD in 2000 (n=7)	50.7 ± 13.6	21.9 ± 2.2
Mean ± SD in 2001 (n=12)	57.0 ± 13.2	26.3 ± 31.2

Table 2. Tables of overlaps of water exchange areas with fish farm sites in the southern Grand Manan Island area in 2000 (top) and 2001 (bottom). Water exchange areas were estimated by 2 methods: 5-km radius buffer zones and model-derived tidal excursion areas. ● indicates that the originating farm's buffer zone overlapped the receiving farm site; ○ indicates that the originating farm's buffer zone approached to within 0.3 km of the receiving farm site; ■ indicates that the originating farm's tidal excursion area overlapped the receiving farm site; □ indicates that the originating farm's tidal excursion area approached to within 0.3 km of the receiving farm site. BMA = Bay Management Area.

2000			Originating farm						
			BMA 20				21	19	
			003	202	270	292	303	316	381
Receiving farm	BMA 20	003	●■	●	●■	●	●		
		202	●	●■	●	●■	●		
		270	●■	●	●■	●□	●		
		292	●	●■	●	●■	●		
	21	303	●	●	●	●	●■	○	
	19	316					○	●■	●■
		381						●■	●■

2001			Originating farm											
			BMA 20				BMA 21					BMA 19		
			003	202	270	292	413	303	403	408	491	316	381	416
Receiving farm	BMA 20	003	●■	●	●■	●	●	●	●	●	●			
		202	●	●■	●	●■	●	●	●	●	●			
		270	●■	●	●■	●□	●	●	●	●	●			
		292	●	●■	●	●■	●	●	●	●	●			
		413	●	●	●	●	●■			○	●			
	BMA 21	303	●	●	●	●		●■	●□	●	●	○		
		403	●	●	●□	●		●	●■	●■	●■	●		
		408	●	●	●■	●	○	●	●■	●■	●■	○		
		491	●	●	●■	●	●	●	●	●	●■			
	BMA 19	316						○	●□	○□		●■	●■	●□
		381										●■	●■	●□
		416										●■	●■	●■

Table 3. Table of overlaps among water exchange areas of licensed salmon farms in the southern Grand Manan Island area in 2000 (top) and 2001 (bottom). Water exchange areas were estimated by 2 methods: 5-km radius circular buffer zones and model-derived tidal excursion areas. ● indicates an overlap of the originating farm's buffer zone with the receiving farm's buffer zone; ■ indicates an overlap of the originating farm's tidal excursion area with the receiving farm's tidal excursion area. BMA = Bay Management Area.

2000			Originating farm						
			BMA 20				21	19	
			003	202	270	292	303	316	381
Receiving farm	BMA 20	003	●■	●	●■	●	●	●	●
		202	●	●■	●	●■	●	●	●
		270	●■	●	●■	●	●	●	●
		292	●	●■	●	●■	●	●	●
	21	303	●	●	●	●	●■	●	●
	19	316	●	●	●	●	●	●■	●■
		381	●	●	●	●	●	●■	●■

2001			Originating farm											
			BMA 20				BMA 21					BMA 19		
			003	202	270	292	413	303	403	408	491	316	381	416
Receiving farm	BMA 20	003	●■	●	●■	●	●	●	●■	●■	●	●	●	
		202	●	●■	●	●■	●	●	●	●	●	●	●	
		270	●■	●	●■	●	●	●	●■	●■	●■	●	●	
		292	●	●■	●	●■	●■	●	●	●	●	●	●	
		413	●	●	●	●■	●■	●	●	●	●			
	BMA 21	303	●	●	●	●	●	●■	●■	●■	●■	●	●	●
		403	●■	●	●■	●	●	●■	●■	●■	●■	●■	●■	●■
		408	●■	●	●■	●	●	●■	●■	●■	●■	●■	●■	●■
		491	●	●	●■	●	●	●■	●■	●■	●■	●	●	
	BMA 19	316	●	●	●	●		●	●■	●■	●	●■	●■	●■
		381	●	●	●	●		●	●■	●■	●	●■	●■	●■
		416						●	●■	●■		●■	●■	●■

Table 4. Summary table of numbers of overlaps of farm water exchange areas with farm sites and water exchange areas in the southern Grand Manan Island area. The values are the mean numbers for each Bay Management Area (BMA) of overlaps of all licensed farms in 2000 and 2001 (see Fig. 6, 10, 17 and 22 for numbers of overlaps per farm). The water exchange areas were estimated by two methods: 5-km radius circular buffer areas (excluding land or areas of water separated from the farm by land) and model-derived tidal exchange estimates. The number of overlaps includes the originating farm, so the maximum possible number of overlaps was 7 in 2000 and 12 in 2001.

		No. of overlaps of each water exchange area with farm sites		No. of overlaps among water exchange areas	
Year	BMA	5-km radius buffer zone (mean ± SD)	Model tidal Excursion area (mean ± SD)	5-km radius buffer zone (mean ± SD)	Model tidal excursion area (mean ± SD)
2000	20	5.0 ± 0.0	2.0 ± 0.0	7.0 ± 0.0	2.0 ± 0.0
2000	21	5.0 ± 0.0	1.0 ± 0.0	7.0 ± 0.0	1.0 ± 0.0
2000	19	2.0 ± 0.0	2.0 ± 0.0	7.0 ± 0.0	2.0 ± 0.0
2000	All	4.1 ± 1.4	1.9 ± 0.3	7.0 ± 0.0	1.9 ± 0.3
2001	20	8.4 ± 1.2	2.2 ± 1.0	10.6 ± 0.8	3.2 ± 1.2
2001	21	8.5 ± 0.5	2.0 ± 0.7	11.8 ± 0.4	6.8 ± 2.3
2001	19	3.3 ± 0.5	2.3 ± 0.9	9.3 ± 2.4	5.0 ± 0.0
2001	All	7.2 ± 2.4	2.2 ± 0.9	10.7 ± 1.6	4.8 ± 2.2

Table 5. Summary table comparing the mean number of farm sites overlapped by each farm's model-derived tidal excursion area with the mean number of tidal excursion areas overlapping each farm site, for licensed finfish farms in the southern Grand Manan Island area in 2000 and 2001. The values are means for each Bay Management Area (BMA) of the numbers of overlaps per farm (see Figs. 17 and 22). The number of overlaps includes the originating farm, so the maximum possible number of overlaps was 7 in 2000 and 12 in 2001.

	No. of receiving farm sites overlapped by each originating farm's tidal excursion area		No. of originating farms' tidal excursion areas overlapping each receiving farm site	
Year	BMA of originating farm	Mean no. of overlaps per originating farm (± SD)	BMA of receiving farm	Mean no. of overlaps per receiving farm (± SD)
2000	20	2.0 ± 0.0	20	2.0 ± 0.0
2000	21	1.0 ± 0.0	21	1.0 ± 0.0
2000	19	2.0 ± 0.0	19	2.0 ± 0.0
2000	All	1.9 ± 0.3	All	1.9 ± 0.3
2001	20	2.2 ± 1.0	20	1.8 ± 0.4
2001	21	2.0 ± 0.7	21	2.5 ± 1.1
2001	19	2.3 ± 0.9	19	2.3 ± 0.5
2001	All	2.2 ± 0.9	All	2.2 ± 0.8

Table 6. Area proportion (%) overlaps among water exchange areas of licensed fish farms in the southern Grand Manan Island area, estimated by 5-km radius buffer zones (top) and model-derived tidal excursion areas (bottom). Values are the proportion (%) of the originating farm's water exchange area which overlaps the receiving farm's water exchange area. Values in bold italics represent new farms licensed in 2001.

Area proportion overlap (%)		Originating farm buffer zone											
		003	202	270	292	***413***	303	***403***	***408***	***491***	316	381	***416***
Receiving farm buffer zone	003	100	88	73	100	***39***	65	***68***	***63***	***70***	17	10	***0***
	202	66	100	51	86	***27***	50	***47***	***42***	***46***	8	2	***0***
	270	81	84	100	90	***58***	46	***56***	***59***	***80***	8	3	***0***
	292	73	96	60	100	***34***	49	***49***	***46***	***54***	7	2	***0***
	413	***47***	***50***	***64***	***56***	***100***	***16***	***28***	***32***	***49***	***0***	***0***	***0***
	303	63	74	40	65	***13***	100	***65***	***51***	***43***	37	26	***7***
	403	***89***	***92***	***67***	***87***	***30***	***87***	***100***	***82***	***72***	***42***	***32***	***10***
	408	***93***	***94***	***79***	***92***	***39***	***78***	***92***	***100***	***86***	***38***	***30***	***9***
	491	***92***	***92***	***94***	***95***	***53***	***59***	***72***	***76***	***100***	***19***	***12***	***0***
	316	25	17	10	14	***0***	54	***45***	***37***	***20***	100	85	***57***
	381	14	4	4	3	***0***	39	***35***	***29***	***14***	88	100	***69***
	416	***0***	***0***	***0***	***0***	***0***	***11***	***11***	***9***	***0***	***60***	***70***	***100***

Area proportion overlap (%)		Originating farm tidal excursion area											
		003	202	270	292	***413***	303	***403***	***408***	***491***	316	381	***416***
Receiving farm tidal excursion area	003	100	0	15	0	***0***	0	***0***	***0***	***0***	0	0	***0***
	202	0	100	0	54	***0***	0	***11***	***7***	***52***	0	0	***0***
	270	47	0	100	0	***0***	0	***4***	***3***	***0***	0	0	***0***
	292	0	80	0	100	***<1***	0	***0***	***0***	***0***	0	0	***0***
	413	***0***	***0***	***0***	***<1***	***100***	***0***	***0***	***0***	***0***	***0***	***0***	***0***
	303	0	0	1	0	***0***	100	***4***	***2***	***<1***	0	0	***0***
	403	***0***	***0***	***25***	***0***	***0***	***18***	***100***	***65***	***62***	***4***	***1***	***1***
	408	***0***	***0***	***24***	***0***	***0***	***12***	***92***	***100***	***62***	***18***	***7***	***7***
	491	***0***	***0***	***49***	***0***	***0***	***<1***	***24***	***17***	***100***	***0***	***0***	***0***
	316	0	0	0	0	***0***	0	***9***	***28***	***0***	100	47	***35***
	381	0	0	0	0	***0***	0	***3***	***17***	***0***	79	100	***73***
	416	***0***	***0***	***0***	***0***	***0***	***0***	***3***	***22***	***0***	***69***	***86***	***100***

Table 7. Number of model-derived particle tracks from each farm which overlapped farm sites (top) and tidal excursion areas (bottom) in the southern Grand Manan Island area. Particles were released from a 200 m × 200 m grid of 36 points located at the farm site and followed for one tidal excursion (12.4 h). Particles were released at hourly intervals over a 12-h period, for a total of 432 particles. The number of particle tracks overlapping the originating farm site was slightly less than 432 for site 202, where the particle release grid extended slightly beyond the farm site boundaries. Figures in bold italics are for new farms licensed in 2001.

No. of overlapping particle tracks		Originating farm tidal excursion area											
		003	202	270	292	***413***	303	***403***	***408***	***491***	316	381	***416***
Receiving farm site	003	432	0	33	0	***0***	0	***0***	***0***	***0***	0	0	***0***
	202	0	417	0	289	***0***	0	***0***	***0***	***0***	0	0	***0***
	270	2	0	432	0	***0***	0	***0***	***0***	***0***	0	0	***0***
	292	0	216	0	432	***0***	0	***0***	***0***	***0***	0	0	***0***
	413	***0***	***0***	***0***	***0***	***432***	***0***	***0***	***0***	***0***	***0***	***0***	***0***
	303	0	0	0	0	***0***	432	***0***	***0***	***0***	0	0	***0***
	403	***0***	***0***	***0***	***0***	***0***	***0***	***432***	***166***	***41***	***0***	***0***	***0***
	408	***0***	***0***	***60***	***0***	***0***	***0***	***221***	***432***	***82***	***0***	***0***	***0***
	491	***0***	***0***	***16***	***0***	***0***	***0***	***0***	***0***	***432***	***0***	***0***	***0***
	316	0	0	0	0	***0***	0	***0***	***0***	***0***	432	0	***0***
	381	0	0	0	0	***0***	0	***0***	***0***	***0***	0	432	***0***
	416	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***110***	***150***	***432***

No. of overlapping particle tracks		Originating farm tidal excursion area											
		003	202	270	292	***413***	303	***403***	***408***	***491***	316	381	***416***
Receiving farm tidal excursion area	003	432	0	232	0	***0***	0	***81***	***42***	***0***	0	0	***0***
	202	0	432	0	432	***0***	0	***0***	***0***	***0***	0	0	***0***
	270	429	0	432	0	***0***	0	***304***	***429***	***432***	0	0	***0***
	292	0	432	0	432	***0***	0	***0***	***0***	***0***	0	0	***0***
	413	***0***	***0***	***0***	***0***	***432***	***0***	***0***	***0***	***0***	***0***	***0***	***0***
	303	0	0	0	0	***0***	432	***136***	***18***	***2***	0	0	***0***
	403	***288***	***0***	***167***	***0***	***0***	***250***	***432***	***432***	***398***	***167***	***43***	***38***
	408	***288***	***0***	***157***	***0***	***0***	***222***	***432***	***432***	***394***	***244***	***118***	***318***
	491	***0***	***0***	***212***	***0***	***0***	***0***	***432***	***432***	***432***	***0***	***0***	***0***
	316	0	0	0	0	***0***	0	***67***	***147***	***0***	432	432	***427***
	381	0	0	0	0	***0***	0	***35***	***72***	***0***	432	432	***432***
	416	***0***	***0***	***0***	***0***	***0***	***0***	***23***	***74***	***0***	***426***	***432***	***432***

Table 8. Overlaps of water exchange areas with farm sites and water exchange areas for finfish farms in Bay Management Area (BMA) 18 (eastern Grand Manan Island area) and BMAs 19-21 (southern Grand Manan Island area).

Farm site in BMA 18	5-km radius buffer zones				Model-derived tidal excursion areas			
	BMA 20	BMA 21	BMA 19	Total	BMA 20	BMA 21	BMA 19	Total
Number of farms in BMAs 19-21 whose site boundaries are overlapped by water exchange areas of farms in BMA 18								
172	0	0	1	1	0	0	2	2
300	0	0	0	0	0	0	2	2
298	0	0	0	0	0	0	0	0
282	0	0	0	0	0	0	0	0
Number of farms in BMAs 19-21 whose water exchange areas overlaps the site boundaries of farms in BMA 18								
172	0	0	1	1	0	0	0	0
300	0	0	0	0	0	0	0	0
298	0	0	0	0	0	0	0	0
282	0	0	0	0	0	0	0	0
Number of farms in BMAs 19-21 whose water exchange areas overlap with water exchange areas of farms in BMA 18								
172	2	3	3	8	0	2	3	5
300	0	2	3	5	0	2	3	5
298	0	1	3	4	0	0	0	0
282	0	1	3	4	0	0	0	0

Table 9. Comparison of characteristics of the water exchange areas of proposed finfish aquaculture site 401 (Ox Head) and existing even year-class site 303 in Bay Management Area 21 (Long Pond Bay area) in 2001. Water exchange areas were estimated using 5-km radius buffer zones (B) and model-derived tidal excursion areas (M). The numbers of overlaps do not include overlaps with the new proposed site or its water exchange area. BMA = Bay Management Area.

Site & water exchange area method	Water exchange area (km^2)	No. of farm sites overlapped				No. of water exchange areas overlapped			
		BMA 20	BMA 21	BMA 19	Total	BMA 20	BMA 21	BMA 19	Total
Site 401									
B	56.8	1	4	2	7*	5	4	3	12
M	23.2	0	1	2	4	1	4	3	8
Site 303									
B	46.8	4	4	0	8	5	4	3	12
M	5.3	0	1	0	1	0	4	0	4

* The 5-km radius buffer zone of proposed site 401 also overlapped farm site 172 in BMA 18 (see Fig. 28).

Table 10. Comparison of characteristics of the water exchange areas of proposed farm sites in Cow Passage in 2001, estimated using 5-km radius buffer zones (B) and model-derived tidal excursion areas (M). The numbers of overlaps do not include the overlaps with the other proposed sites in Cow Passage or with their water exchange areas. BMA = Bay Management Area.

Site	Water exchange area estimate method	Water exchange area (km^2)	No. of farm sites overlapped				No. of water exchange areas overlapped			
			BMA 20	BMA 21	BMA 19	BMA 18	BMA 20	BMA 21	BMA 19	BMA 18
402	B[1]	67.5	0	0	3	4	0	3	3	4
418	B[1]	65.6	0	0	3	4	1	3	3	4
419	B[1]	64.3	0	0	3	4	0	3	3	4
402	M	1.3	0	0	0	0	0	0	0	0
418	M[2]	26.3	0	0	3	0	0	2	3	2
419	M[3]	23.2	0	0	3	1	0	2	3	4

[1] The 5-km radius buffer zones of all three proposed sites also overlapped the other two proposed sites and their buffer zones (see Fig. 29).

[2] The model-derived tidal excursion area of site 418 also overlapped proposed site 419 and the tidal excursion areas of proposed sites 402 and 418 (see Fig. 29).

[3] The model-derived tidal excursion area of site 419 also overlapped proposed site 418 and the tidal excursion areas of proposed sites 402 and 418 (see Fig. 29).

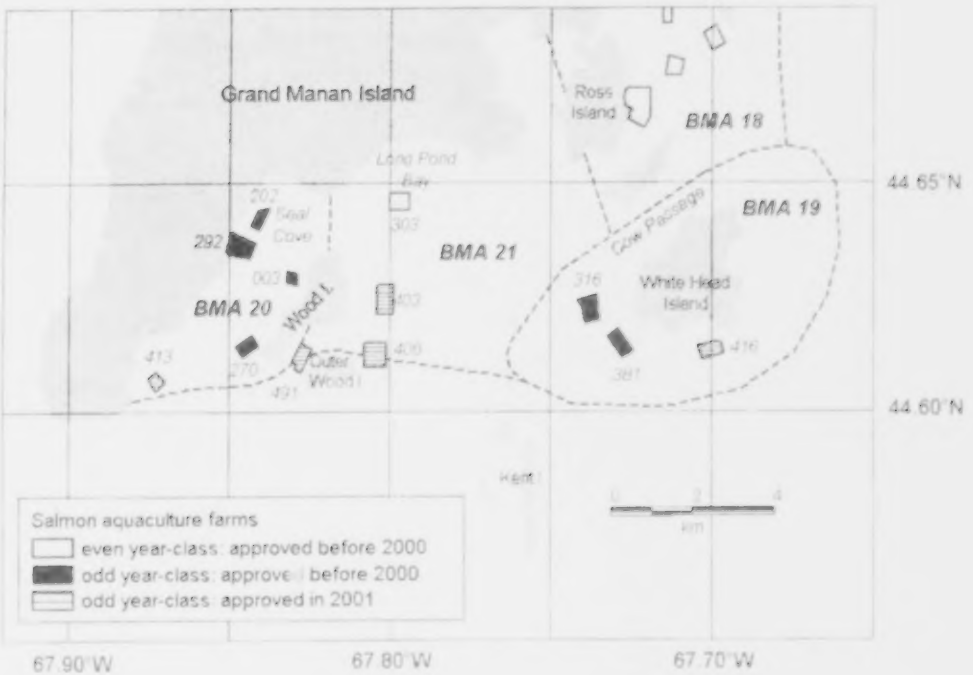

Fig. 1. Map of the southern Grand Manan Island area showing licensed salmon farm sites and Bay Management Areas (BMAs). Site identification numbers are shown beside the farm sites.

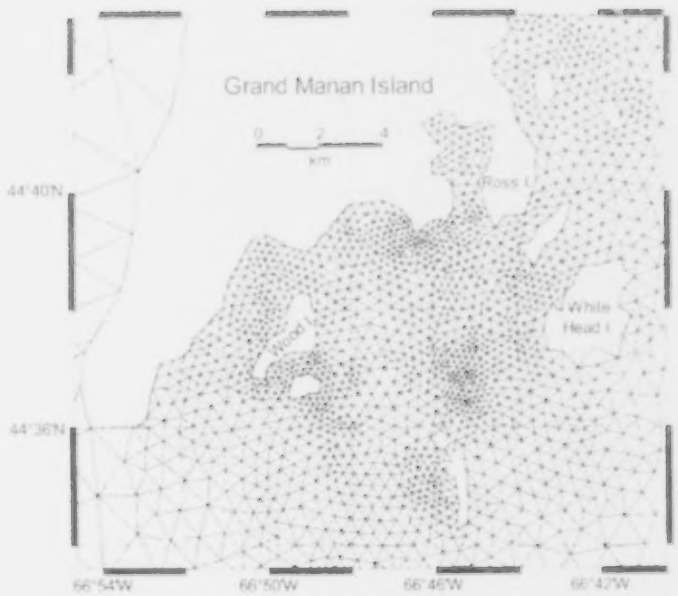

Fig. 2. Map showing finite elements for the circulation model in the southern Grand Manan area (see text for more information).

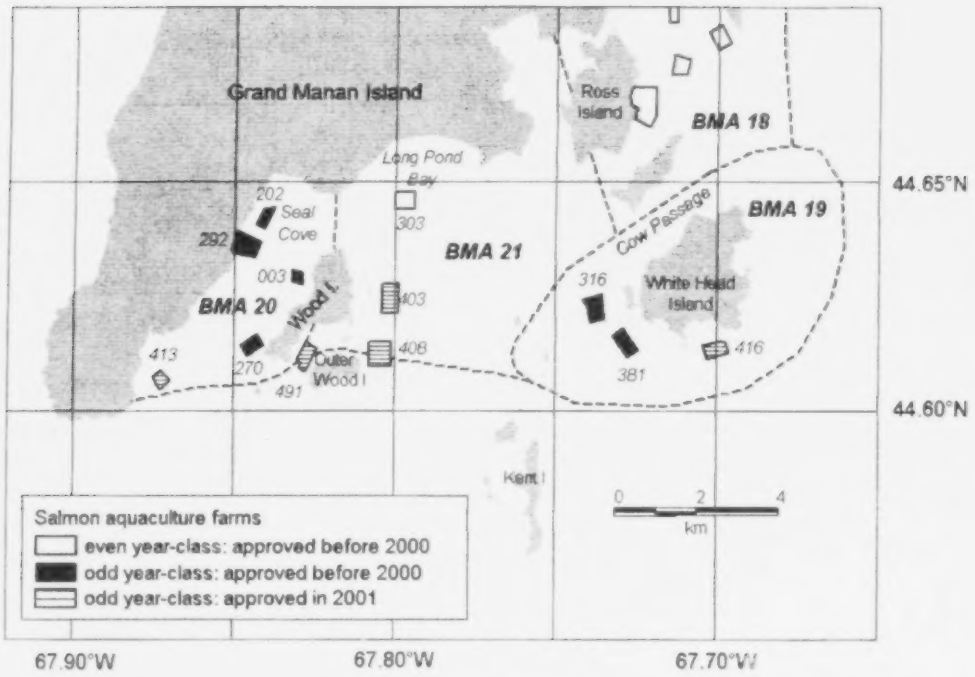

Fig. 1. Map of the southern Grand Manan Island area showing licensed salmon farm sites and Bay Management Areas (BMAs). Site identification numbers are shown beside the farm sites.

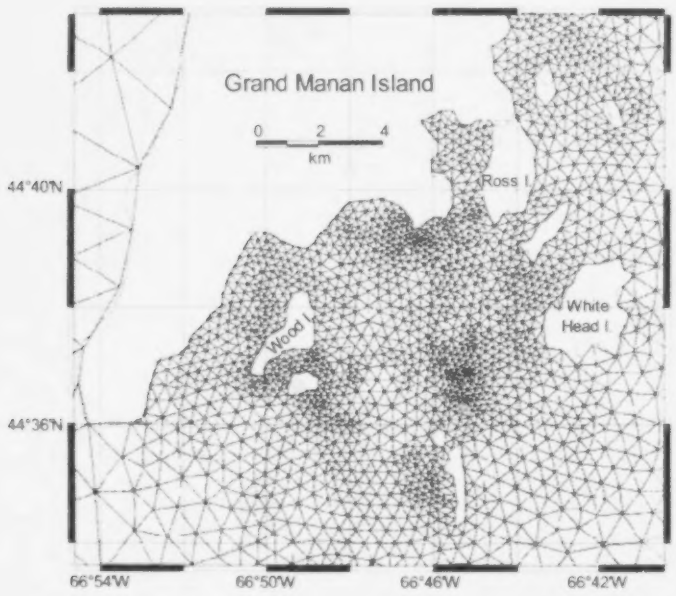

Fig. 2. Map showing finite elements for the circulation model in the southern Grand Manan area (see text for more information).

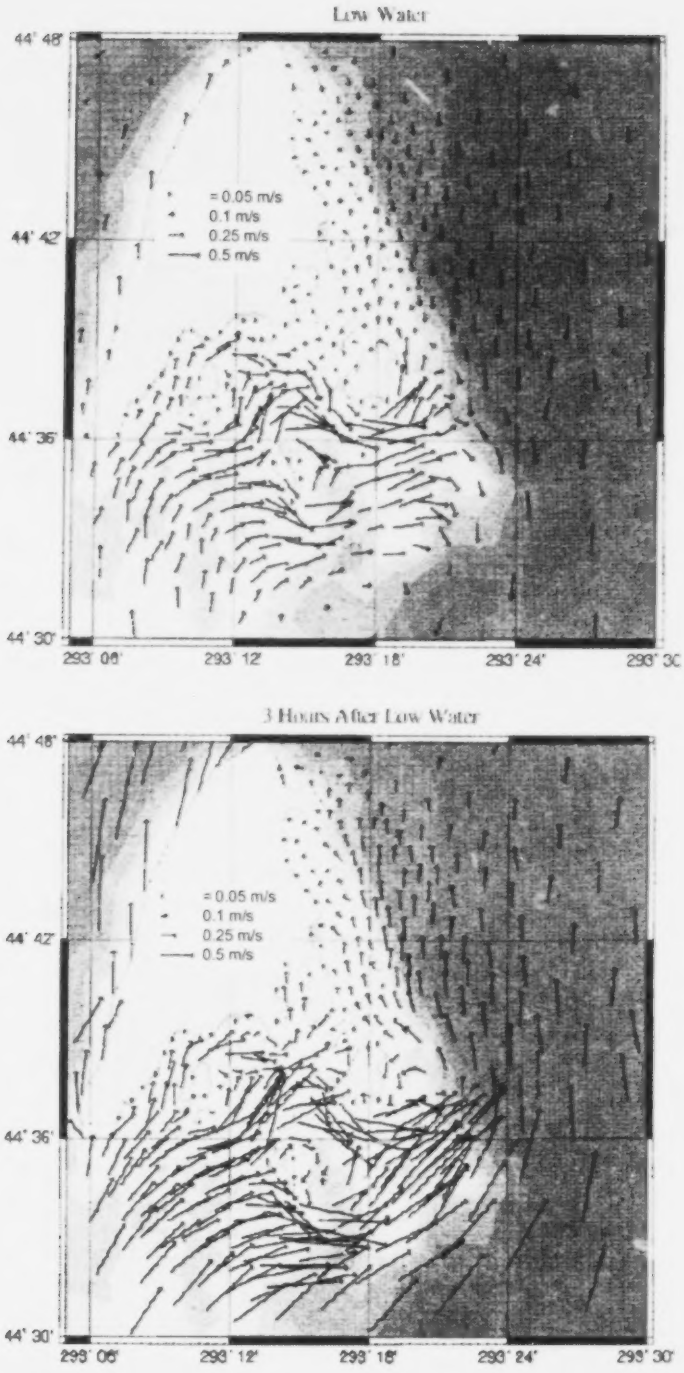

Fig. 3a. Water currents in the Grand Manan Island area, as predicted by the circulation model (see text for more information): low tide and peak flood tide (3 h after low tide).

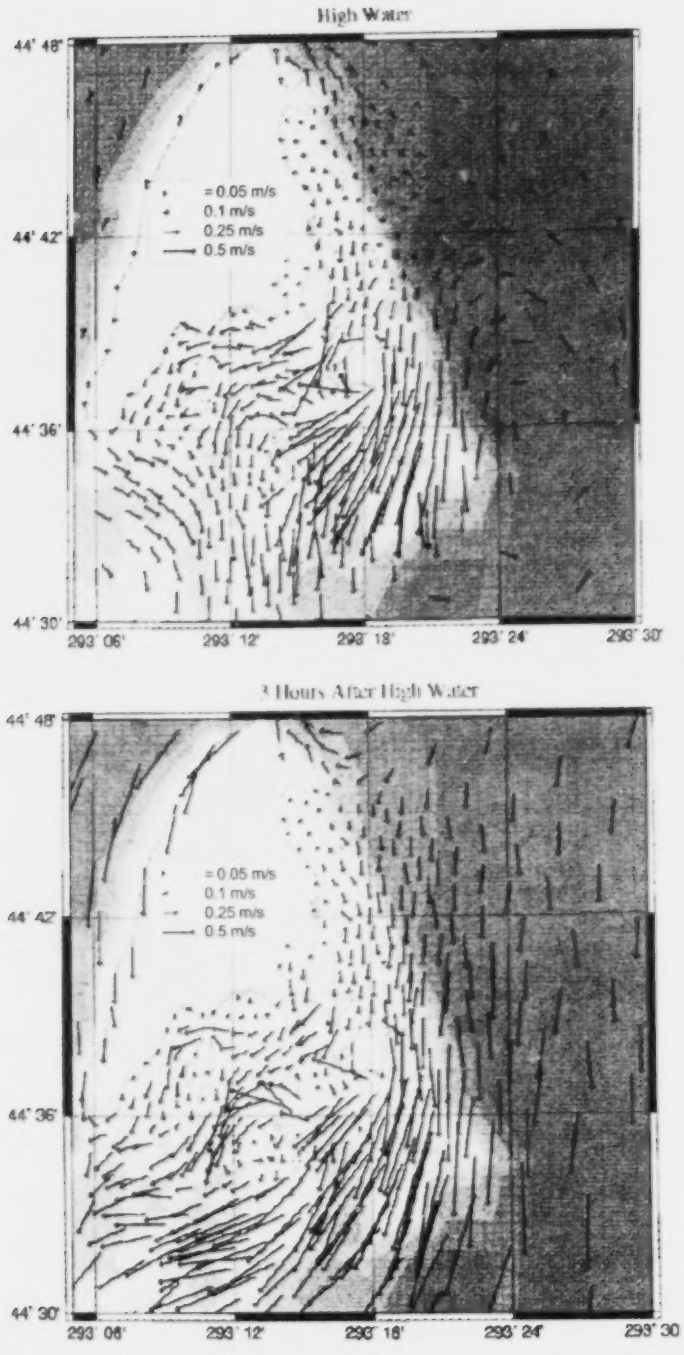

Fig. 3b. Water currents in the Grand Manan Island area, as predicted by the circulation model: high tide and peak ebb tide (3 h after high tide).

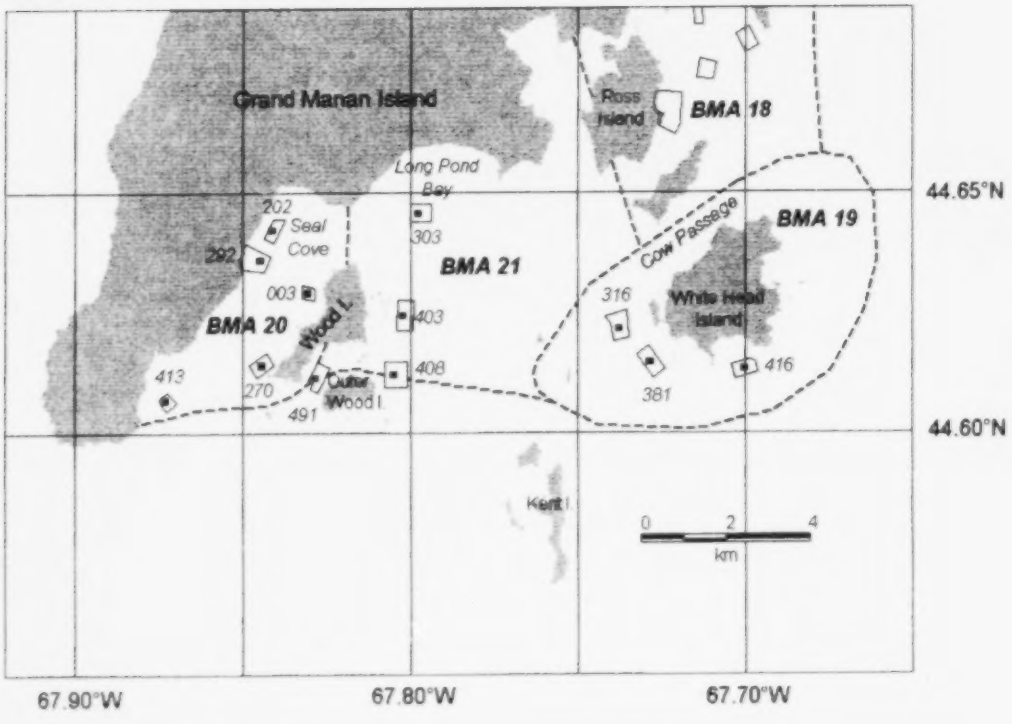

Fig. 4. Map of the southern Grand Manan Island area showing licensed salmon farms (white polygons) in 2001, Bay Management Areas (BMAs), and locations of model particle release grids (small black squares). Site identification numbers are shown beside the farm sites.

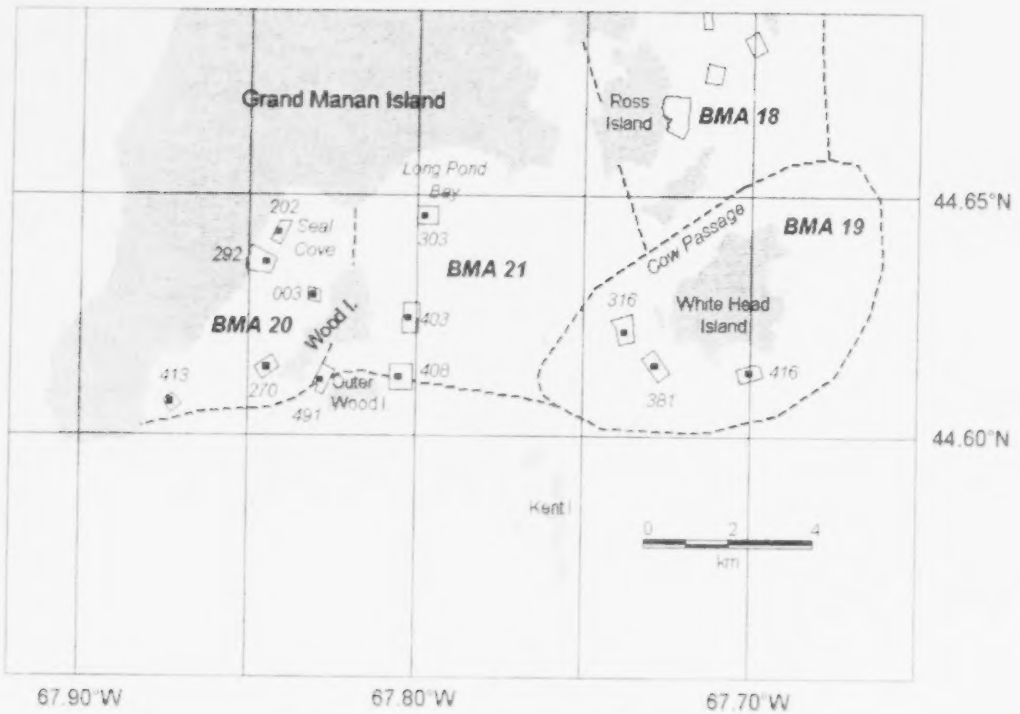

Fig. 4. Map of the southern Grand Manan Island area showing licensed salmon farms (white polygons) in 2001, Bay Management Areas (BMAs), and locations of model particle release grids (small black squares). Site identification numbers are shown beside the farm sites.

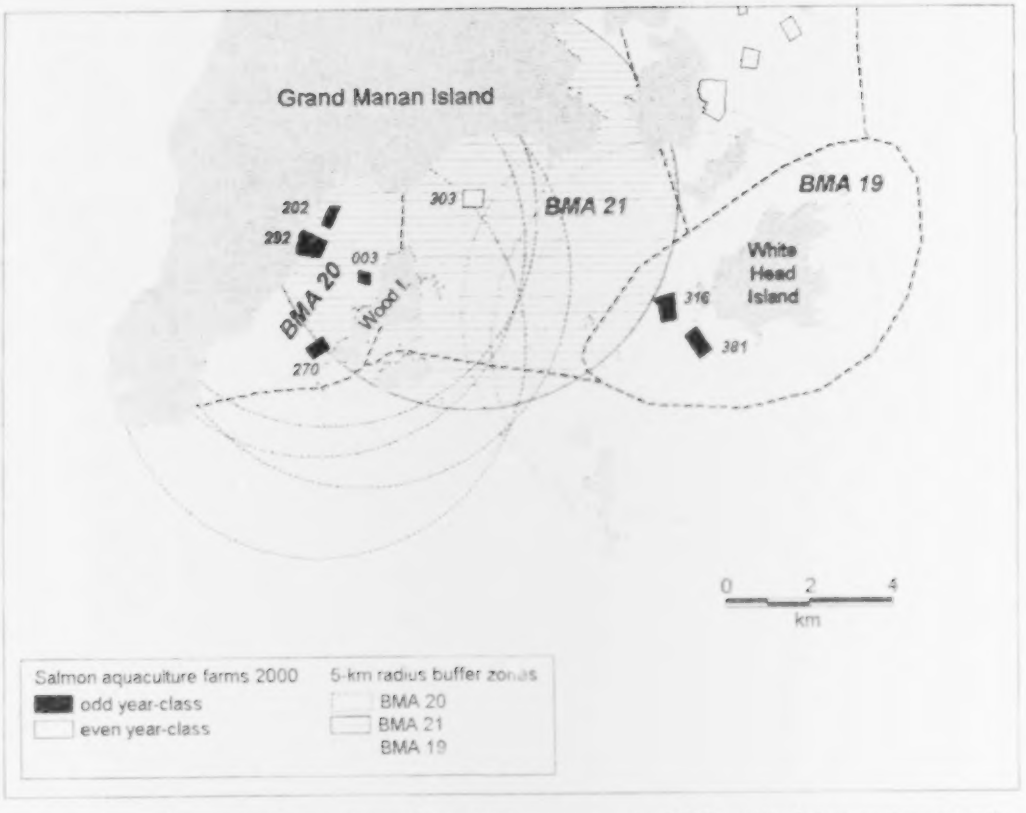

Fig. 5. Salmon farms in the southern Grand Manan area in 2000, with 5-km radius circular buffer zones around each farm. BMA = Bay Management Area. Site identification numbers are shown beside the farm sites.

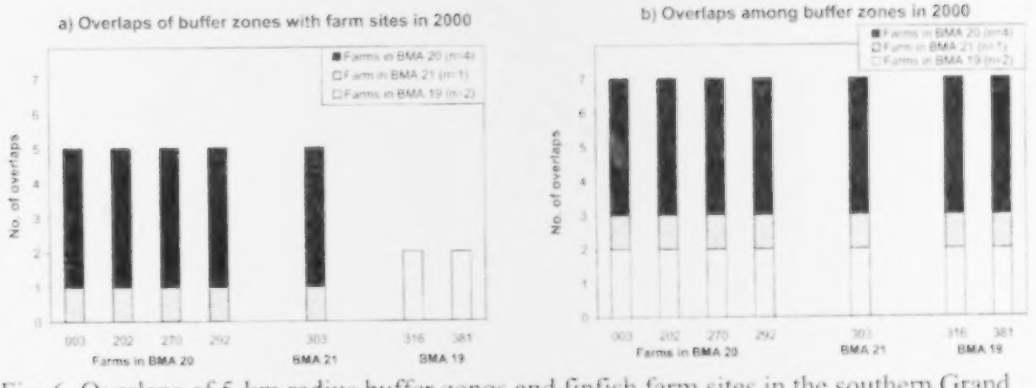
a) Overlaps of buffer zones with farm sites in 2000
No. of overlaps
003 202 270 292 303 316 381
Farms in BMA 20
BMA 21
BMA 19
b) Overlaps among buffer zones in 2000
No. of overlaps
003 202 270 292 303 316 381
Farms in BMA 20
BMA 21
BMA 19

Fig. 6. Overlaps of 5-km radius buffer zones and finfish farm sites in the southern Grand Manan Island area in 2000: a) number of overlaps of each buffer zone with farm sites (or the number of buffer zones overlapping each farm site); b) number of overlaps among buffer zones. The numbers include overlaps with the originating farm. The maximum possible number of overlaps is 7.

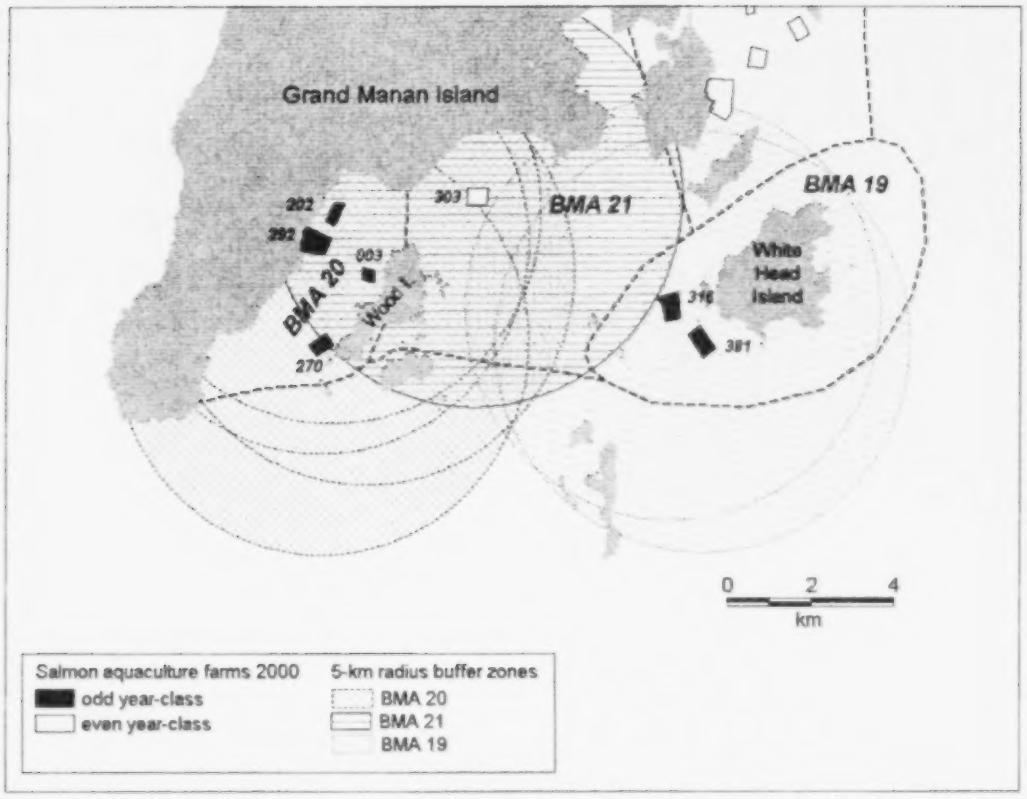

Fig. 5. Salmon farms in the southern Grand Manan area in 2000, with 5-km radius circular buffer zones around each farm. BMA = Bay Management Area. Site identification numbers are shown beside the farm sites.

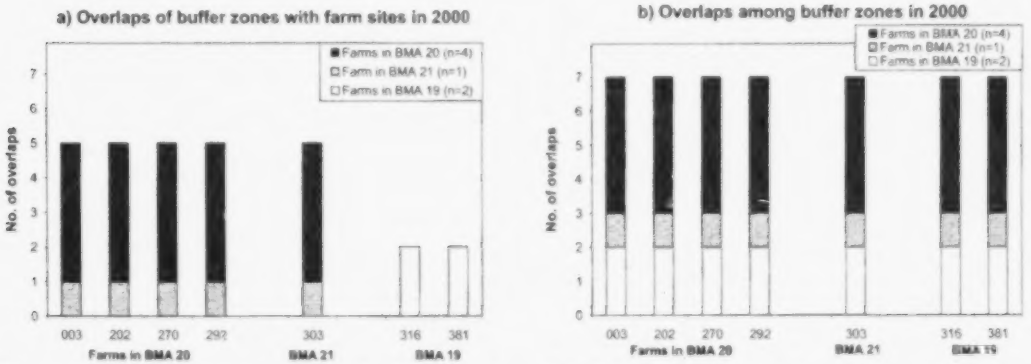
a) Overlaps of buffer zones with farm sites in 2000
Farms in BMA 20 (n=4)
Farm in BMA 21 (n=1)
Farms in BMA 19 (n=2)
No. of overlaps
003 202 270 292 303 316 381
Farms in BMA 20
BMA 21
BMA 19
b) Overlaps among buffer zones in 2000
Farms in BMA 20 (n=4)
Farm in BMA 21 (n=1)
Farms in BMA 19 (n=2)
No. of overlaps
003 202 270 292 303 316 381
Farms in BMA 20
BMA 21
BMA 19

Fig. 6. Overlaps of 5-km radius buffer zones and finfish farm sites in the southern Grand Manan Island area in 2000: a) number of overlaps of each buffer zone with farm sites (or the number of buffer zones overlapping each farm site); b) number of overlaps among buffer zones. The numbers include overlaps with the originating farm. The maximum possible number of overlaps is 7.

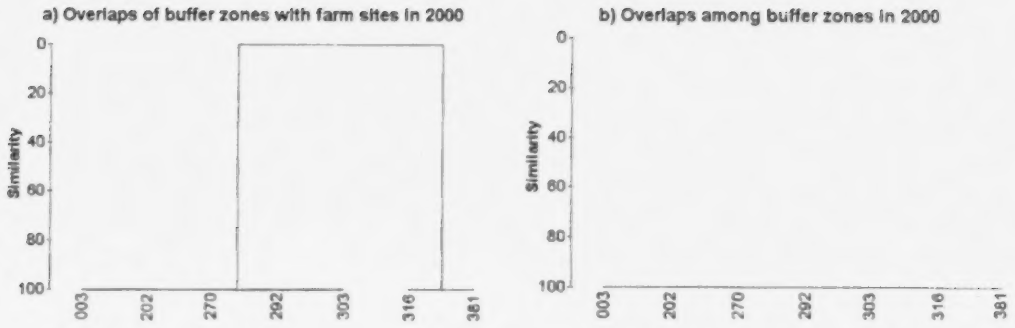

Fig. 7. Cluster analyses using Bray-Curtis similarity coefficients calculated on the presence or absence of overlaps using 5-km radius buffer zones, for finfish farms in the southern Grand Manan Island area in 2000: a) overlaps of 5-km radius buffer zones with farm sites; b) overlaps among buffer zones.

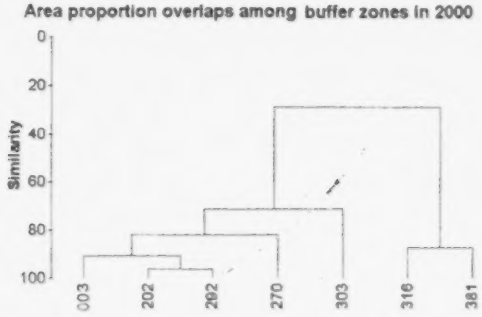

Fig. 8. Cluster analysis using Bray-Curtis similarity coefficients calculated on the areal extent of overlaps among 5-km radius buffer zones, for finfish farms in the southern Grand Manan Island area in 2000. The coefficients were calculated on the areal proportion of the originating farm's buffer zone which overlapped the buffer zones of farms operating in the area.

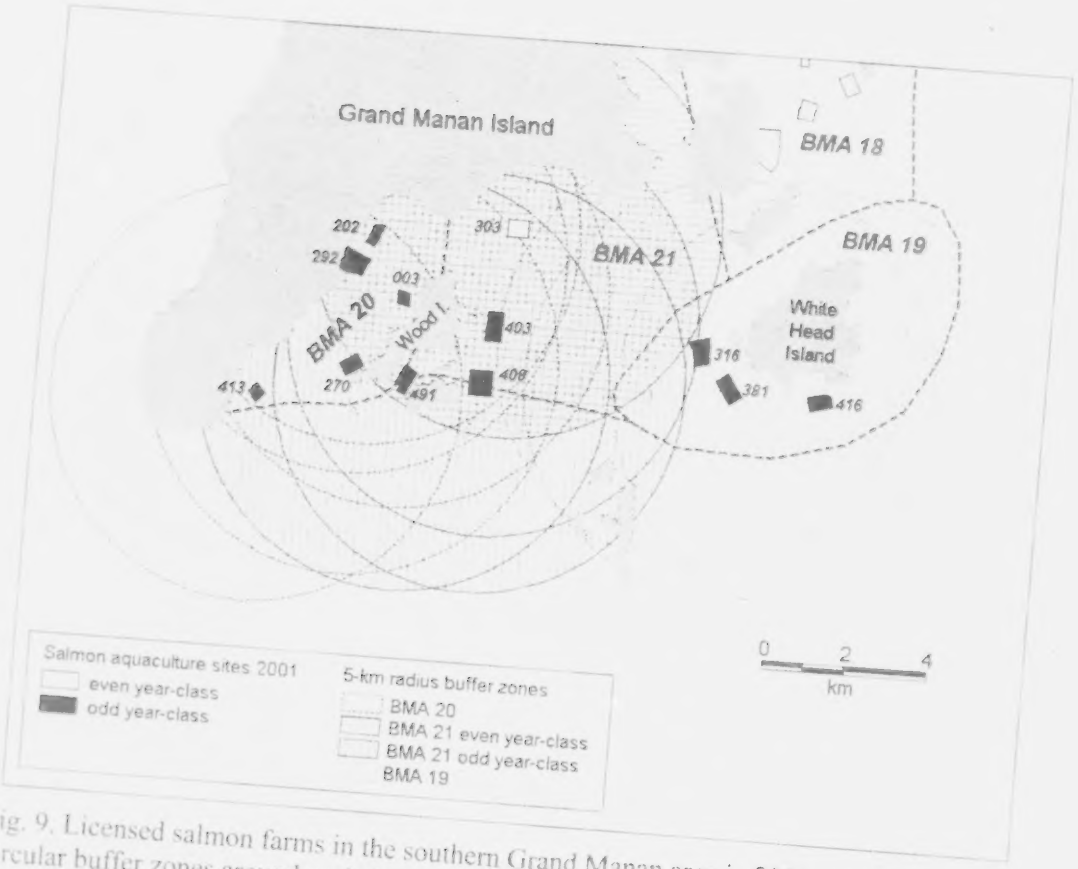

Fig. 9. Licensed salmon farms in the southern Grand Manan area in 2001, with 5-km radius circular buffer zones around each farm. BMA = Bay Management Area. Site identification numbers are shown beside the farm sites.

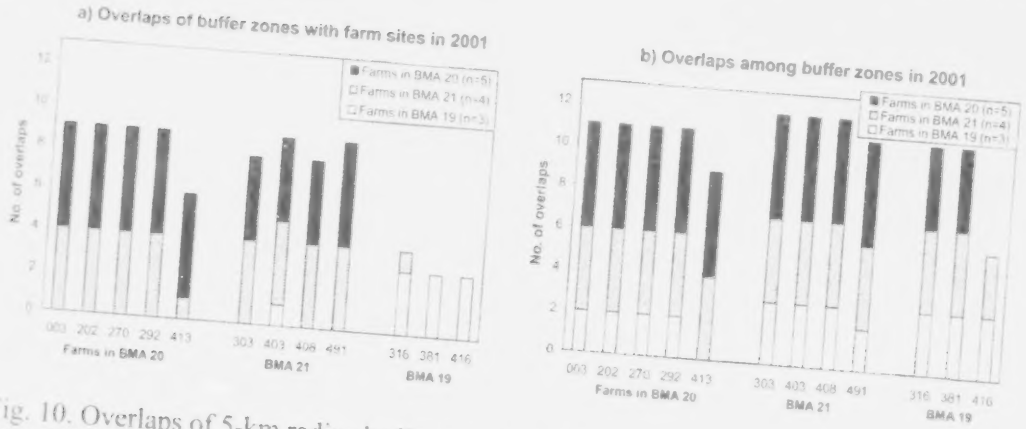
a) Overlaps of buffer zones with farm sites in 2001
Farms in BMA 20 (n=5)
Farms in BMA 21 (n=4)
Farms in BMA 19 (n=3)
No. of overlaps
003 202 270 292 413
303 403 408 491
316 381 416
Farms in BMA 20
BMA 21
BMA 19
b) Overlaps among buffer zones in 2001
Farms in BMA 20 (n=5)
Farms in BMA 21 (n=4)
Farms in BMA 19 (n=3)
No. of overlaps
003 202 270 292 413
303 403 408 491
316 381 416
Farms in BMA 20
BMA 21
BMA 19

Fig. 10. Overlaps of 5-km radius buffer zones and finfish farm sites in the southern Grand Manan Island area in 2001: a) number of overlaps of each buffer zone with farm sites (or the number buffer zones overlapping each farm site); b) number of overlaps among buffer zones. The numbers include overlaps with the originating farm. The maximum possible number of overlaps is 12.

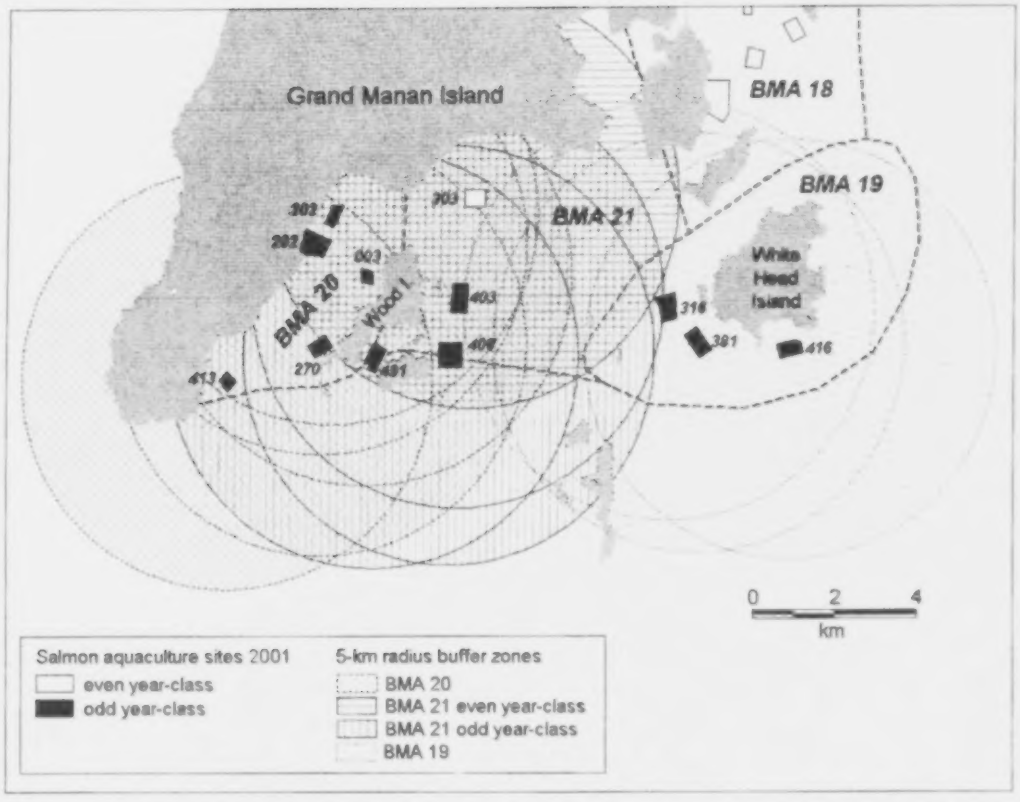

Fig. 9. Licensed salmon farms in the southern Grand Manan area in 2001, with 5-km radius circular buffer zones around each farm. BMA = Bay Management Area. Site identification numbers are shown beside the farm sites.

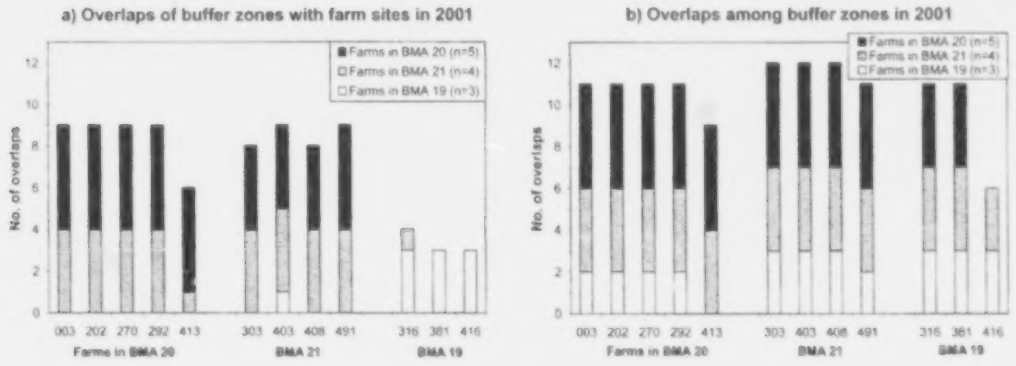
a) Overlaps of buffer zones with farm sites in 2001
Farms in BMA 20 (n=5)
Farms in BMA 21 (n=4)
Farms in BMA 19 (n=3)
No. of overlaps
003 202 270 292 413
303 403 408 491
316 381 416
Farms in BMA 20
BMA 21
BMA 19
b) Overlaps among buffer zones in 2001
Farms in BMA 20 (n=5)
Farms in BMA 21 (n=4)
Farms in BMA 19 (n=3)
No. of overlaps
003 202 270 292 413
303 403 408 491
316 381 416
Farms in BMA 20
BMA 21
BMA 19

Fig. 10. Overlaps of 5-km radius buffer zones and finfish farm sites in the southern Grand Manan Island area in 2001: a) number of overlaps of each buffer zone with farm sites (or the number buffer zones overlapping each farm site); b) number of overlaps among buffer zones. The numbers include overlaps with the originating farm. The maximum possible number of overlaps is 12.

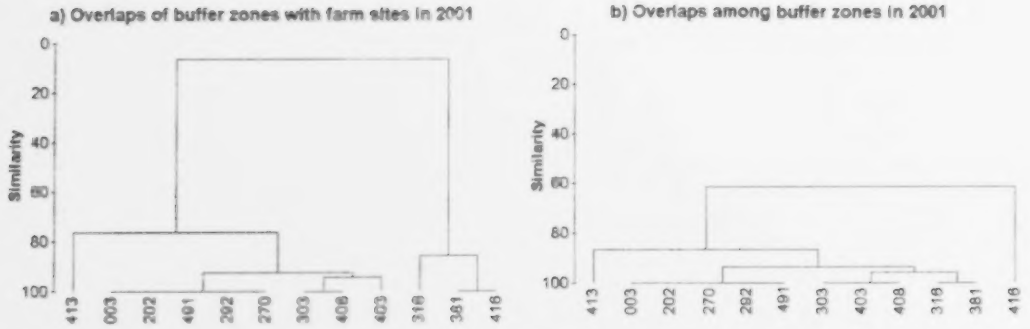

Fig. 11. Cluster analyses using Bray-Curtis similarity coefficients calculated on the presence or absence of overlaps using 5-km radius buffer zones, for finfish farms in the southern Grand Manan Island area in 2001: a) overlaps of 5-km radius buffer zones with farm sites: b) overlaps among buffer zones.

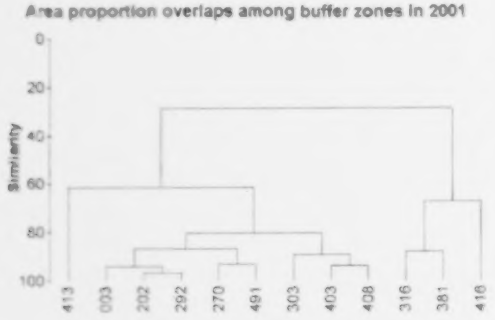

Fig. 12. Cluster analysis using Bray-Curtis similarity coefficients calculated on the areal extent of overlaps among 5-km radius buffer zones, for finfish farms in the southern Grand Manan Island area in 2001. The coefficients were calculated on the areal proportion of the originating farm's buffer zone which overlapped the buffer zones of farms operating in the area.

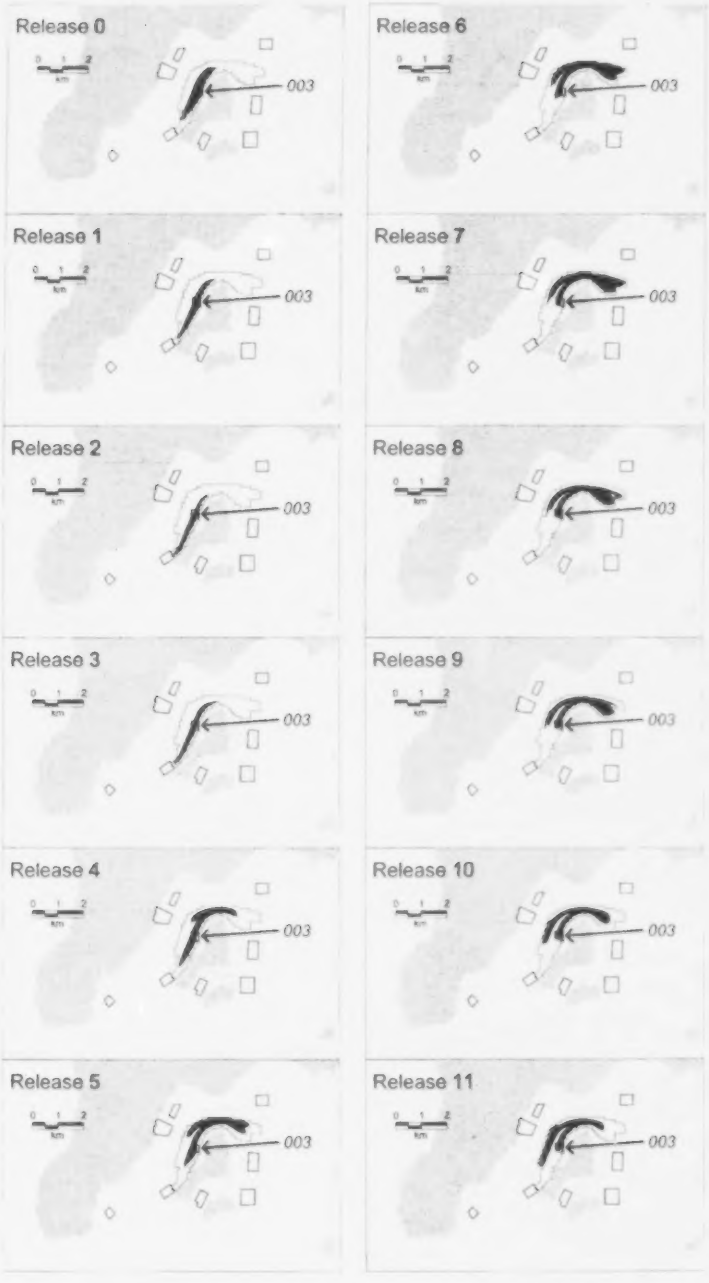

Fig. 13a. Model particle tracks for each hourly release (0 to 11) from farm 003 in Bay Management Area 20. Each release consists of 36 particle tracks, released from a 200 m × 200 m grid located at the farm site, and tracked for one tidal excursion (12.4 h) or until the particle hit the shore if that happened first. Finfish farms are shown as small white polygons; the originating farm is indicated by an arrow. The larger polygon is the outline of the total tidal excursion area.

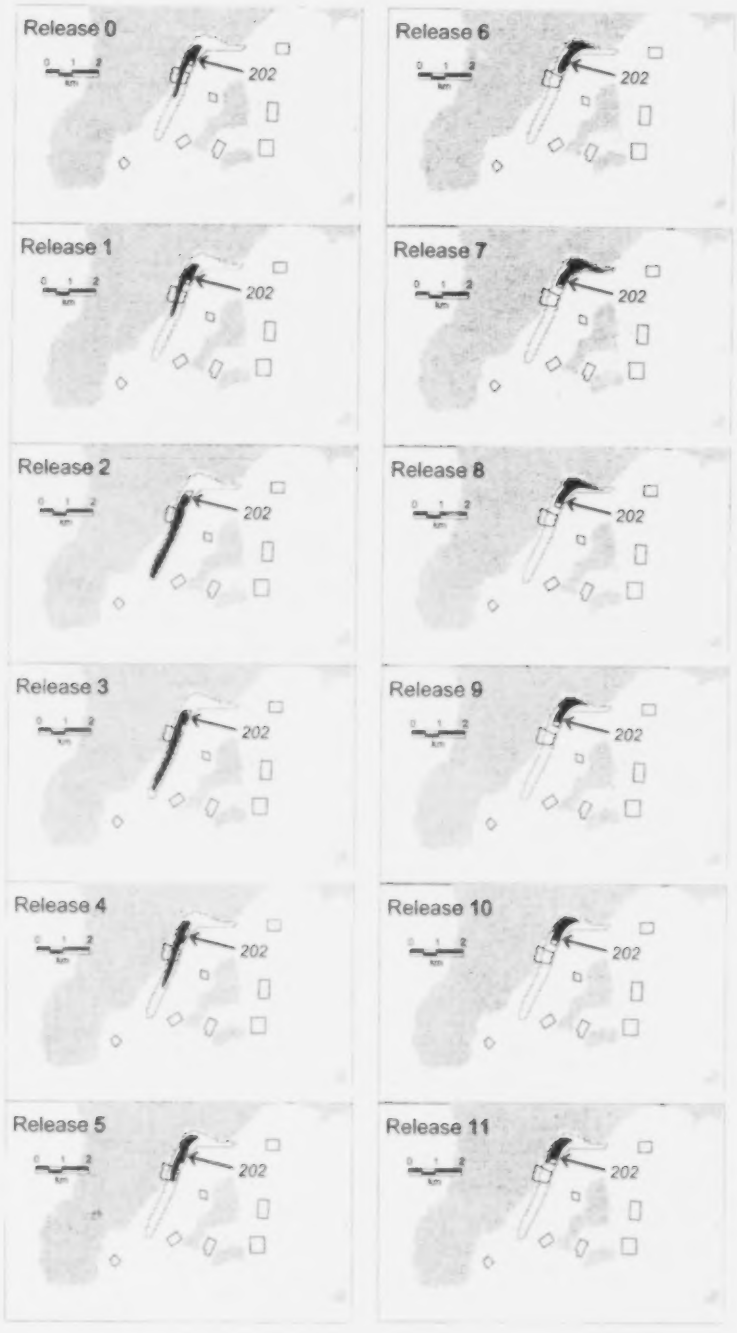

Fig. 13b. Model particle tracks for each hourly release (0 to 11) from farm 202 in Bay Management Area 20. See caption for Fig. 13a.

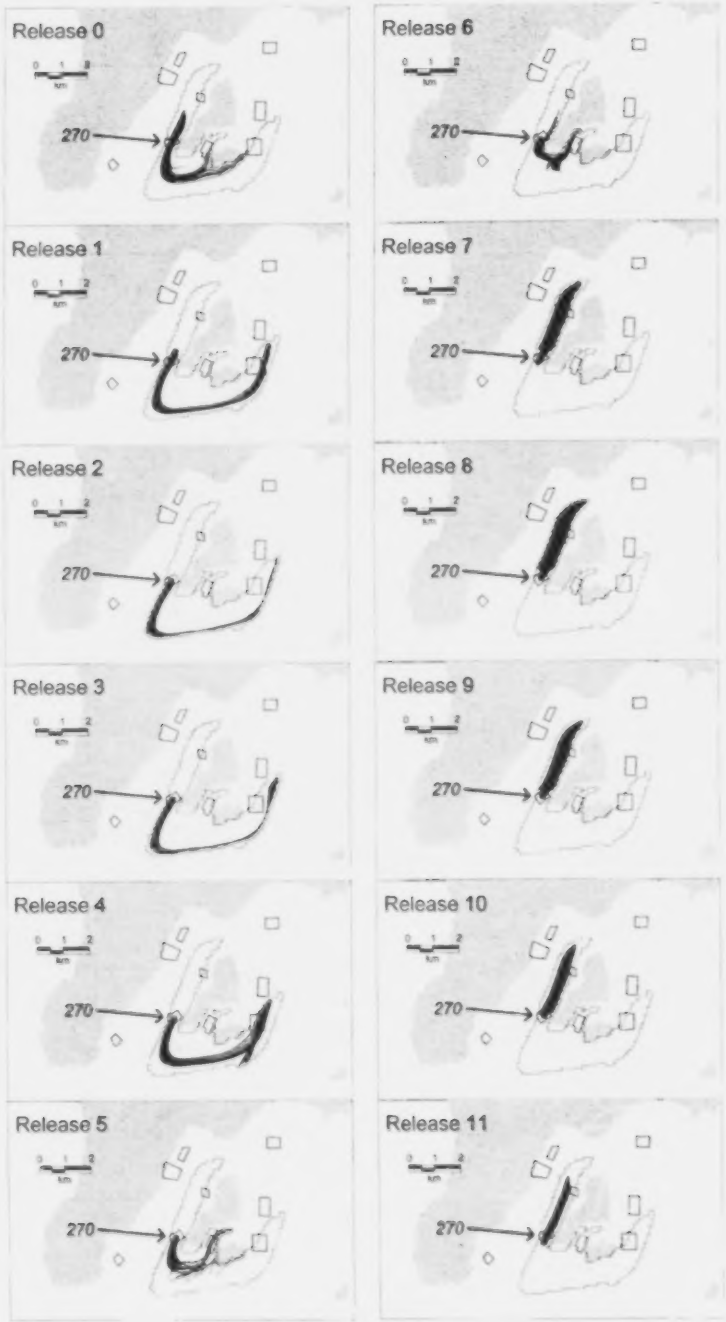

Fig. 13c. Model particle tracks for each hourly release (0 to 11) from farm 270 in Bay Management Area 20. See caption for Fig. 13a.

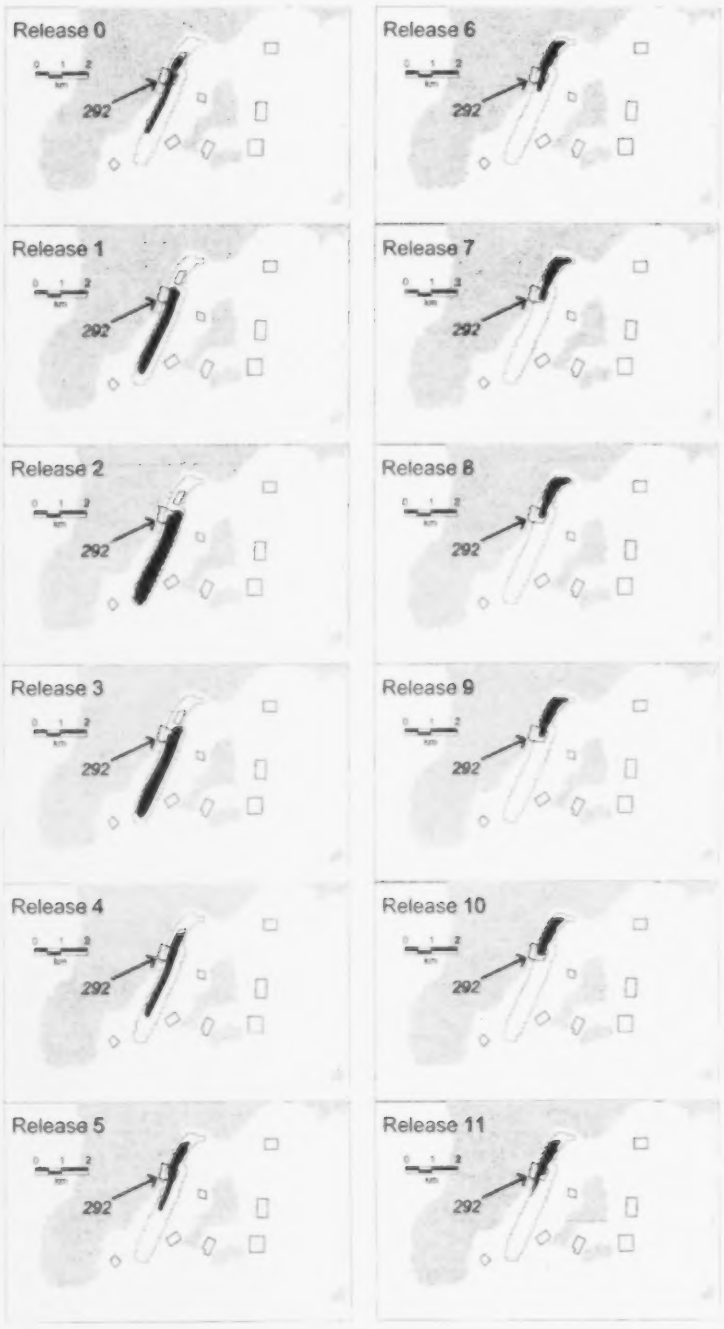

Fig. 13d. Model particle tracks for each hourly release (0 to 11) from farm 292 in Bay Management Area 20. See caption for Fig. 13a.

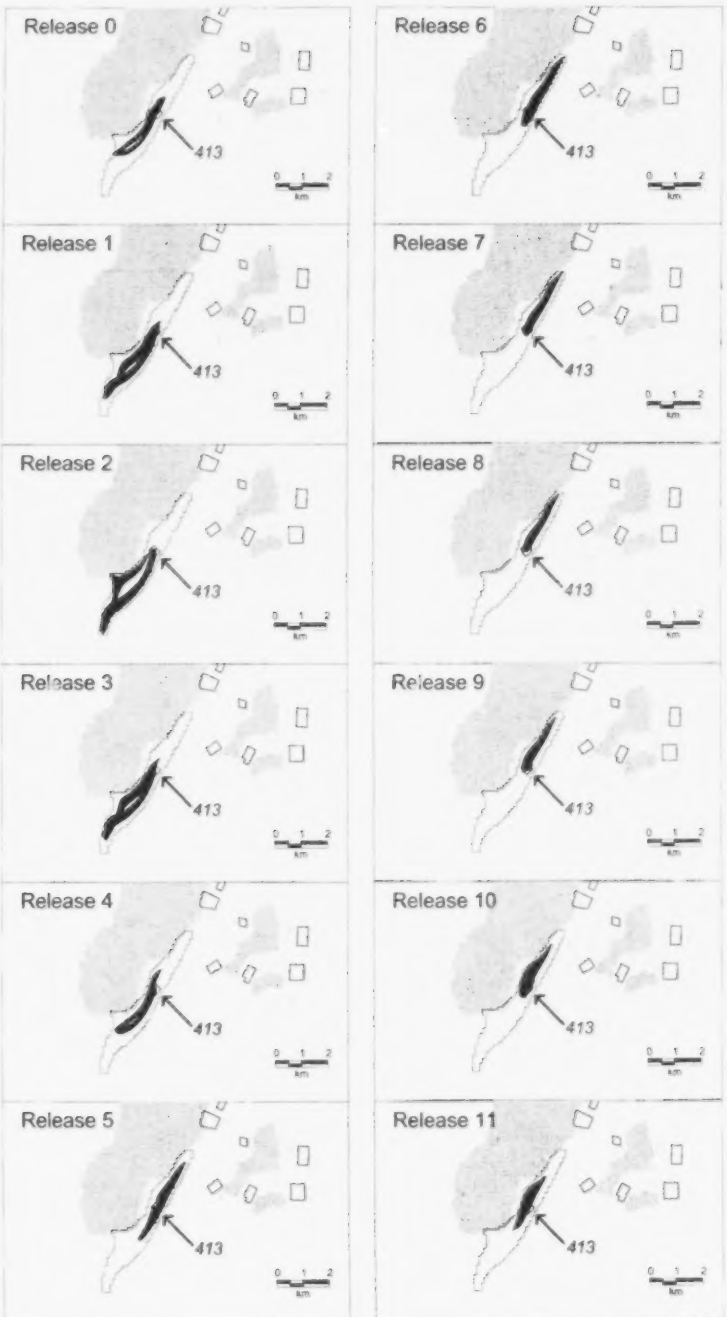

Fig. 13e. Model particle tracks for each hourly release (0 to 11) from farm 413 in Bay Management Area 20. See caption for Fig. 13a.

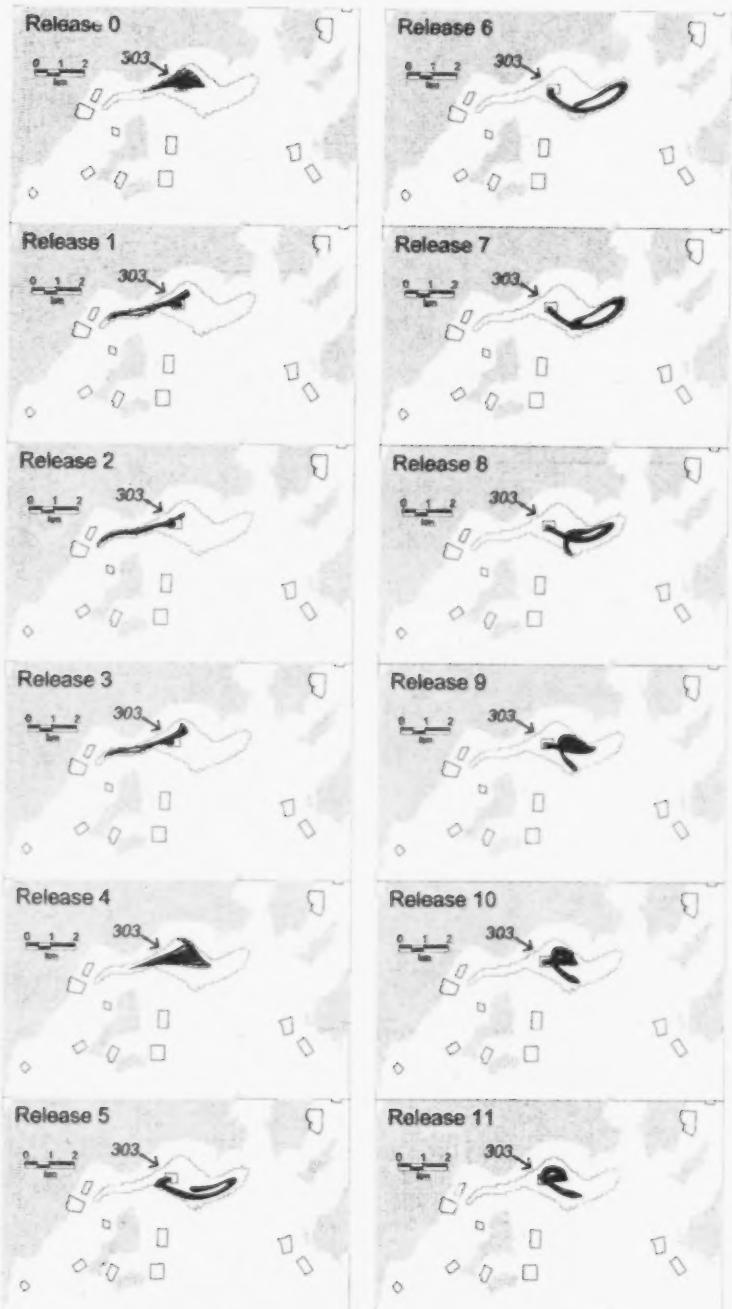

Fig. 13f. Model particle tracks for each hourly release (0 to 11) from farm 303 in Bay Management Area 21. See caption for Fig. 13a.

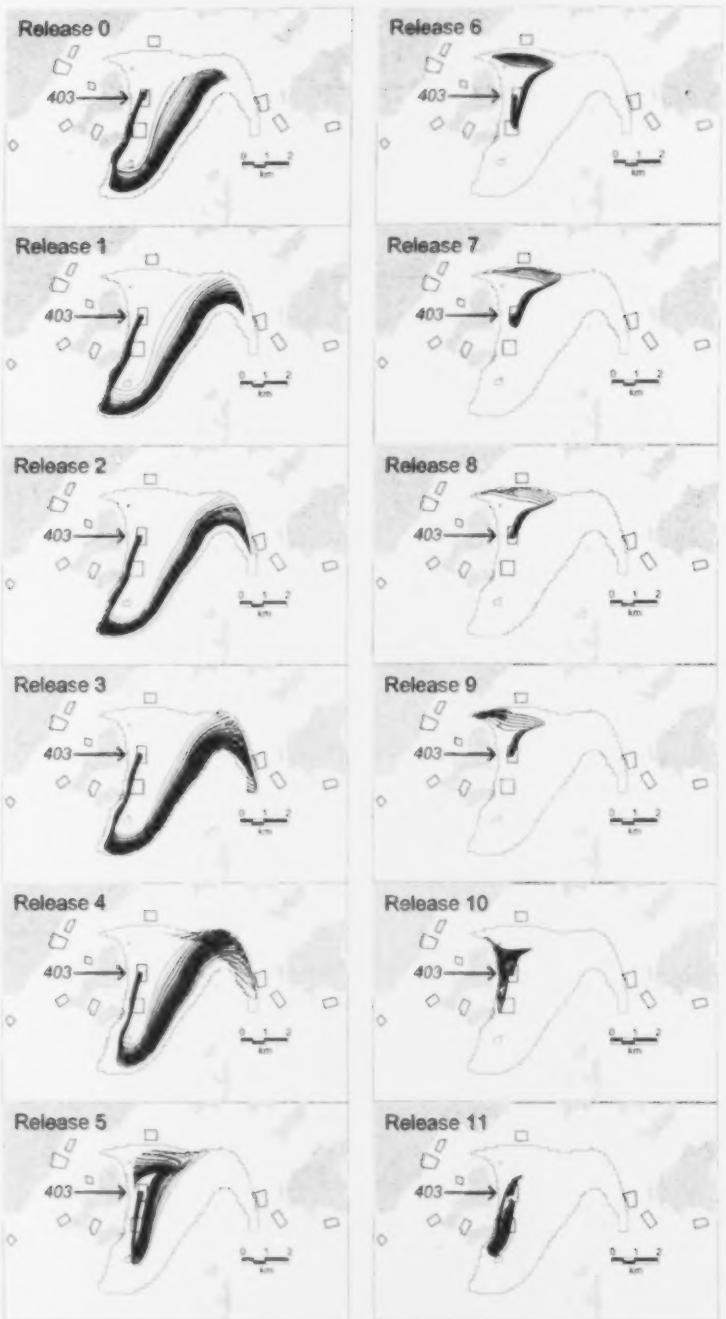

Fig. 13g. Model particle tracks for each hourly release (0 to 11) from farm 403 in Bay Management Area 21. See caption for Fig. 13a.

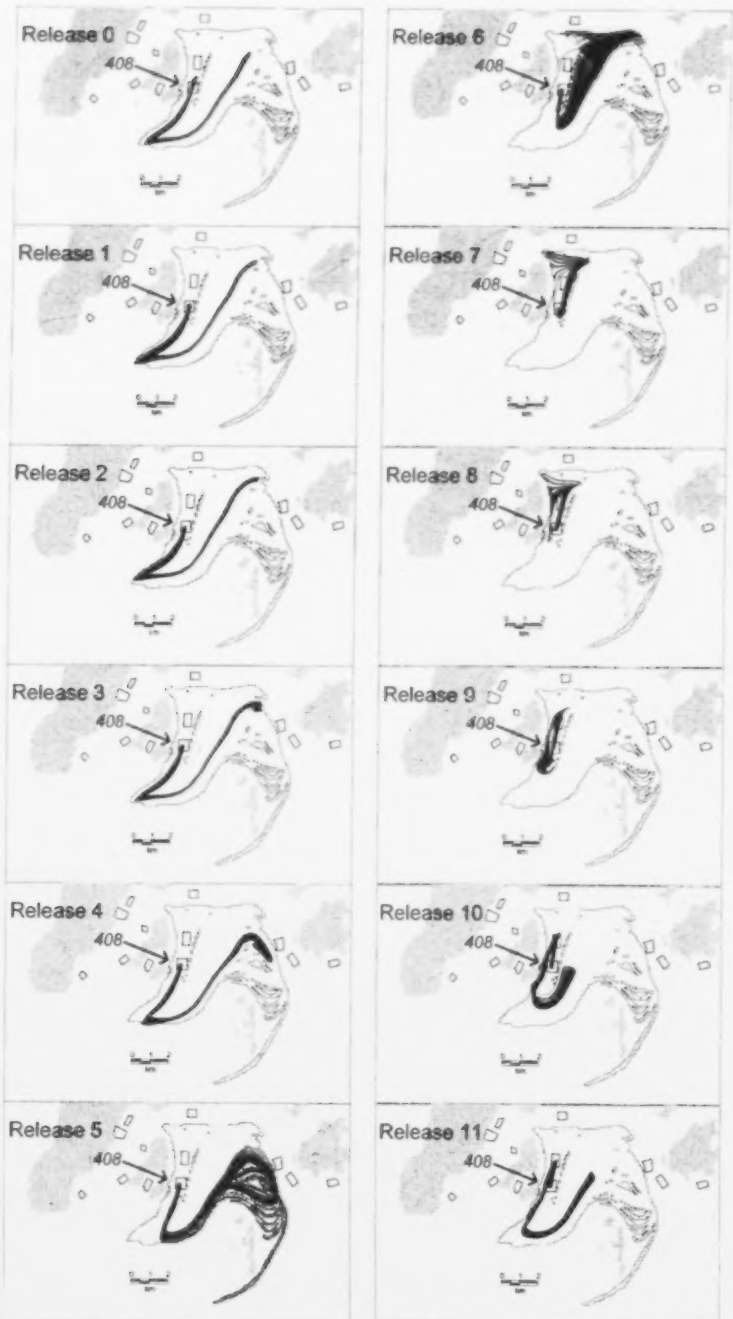

Fig. 13h. Model particle tracks for each hourly release (0 to 11) from farm 408 in Bay Management Area 21. See caption for Fig. 13a.

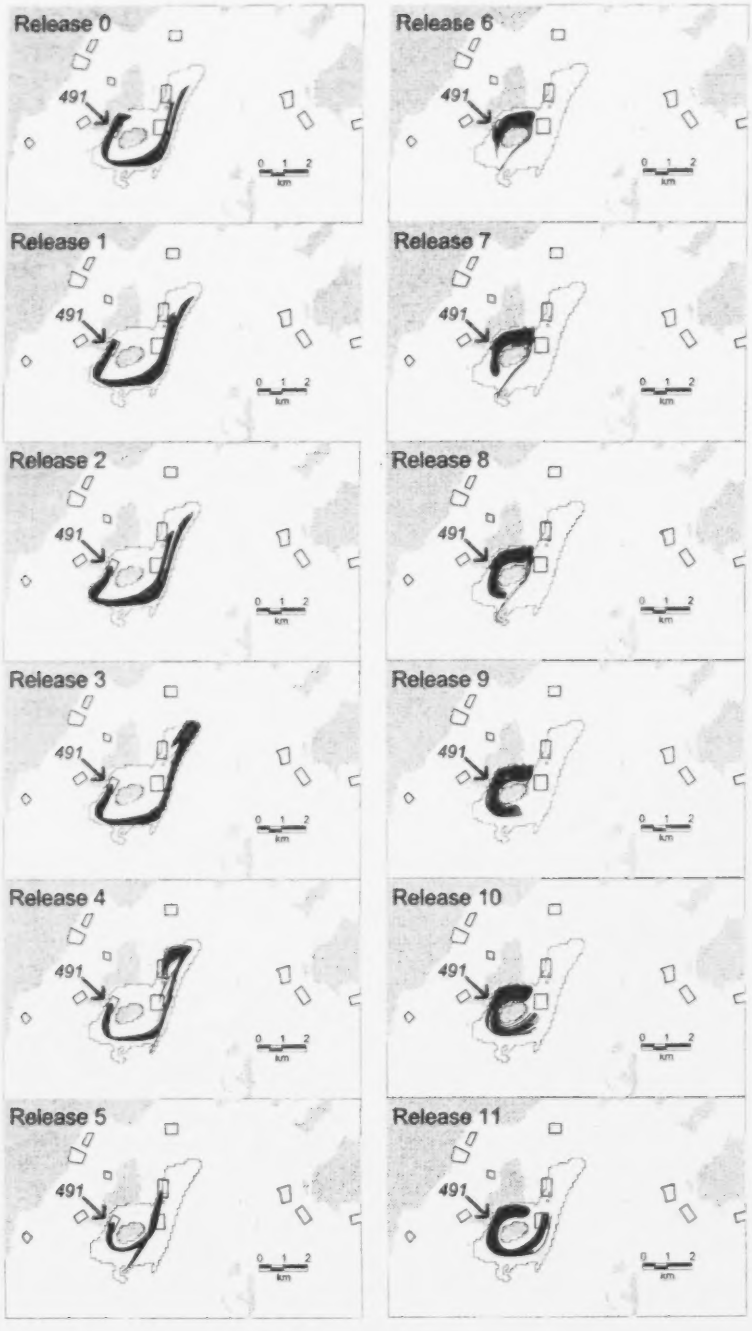

Fig. 13i. Model particle tracks for each hourly release (0 to 11) from farm 491 in Bay Management Area 21. See caption for Fig. 13a.

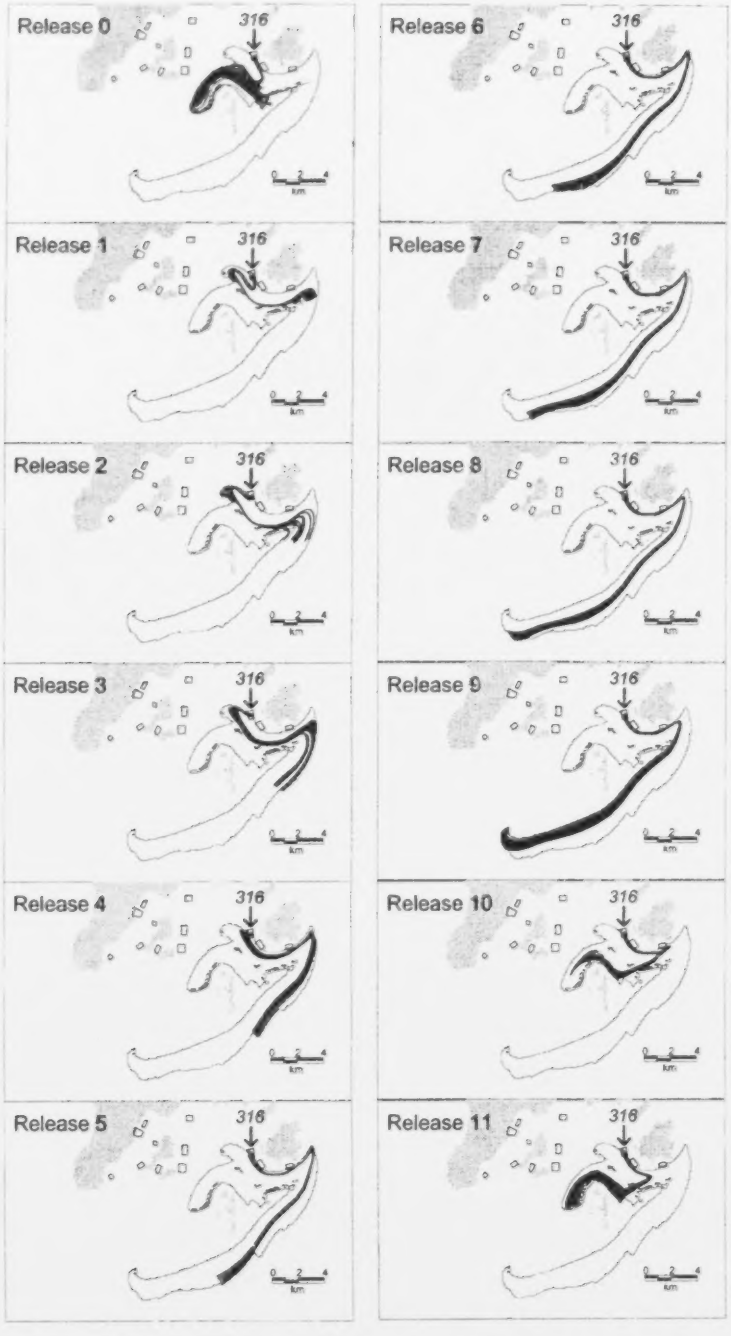

Fig. 13j. Model particle tracks for each hourly release (0 to 11) from farm 316 in Bay Management Area 19. See caption for Fig. 13a.

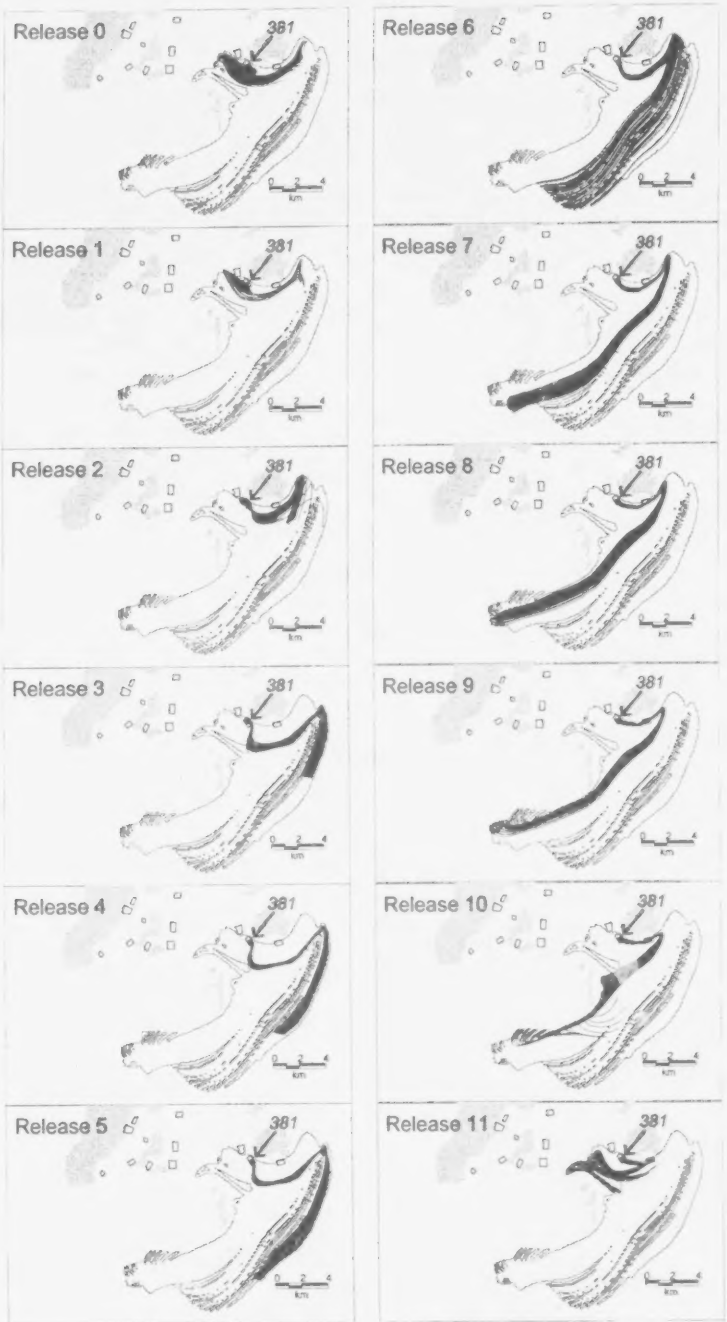

Fig. 13k. Model particle tracks for each hourly release (0 to 11) from farm 381 in Bay Management Area 19. See caption for Fig. 13a.

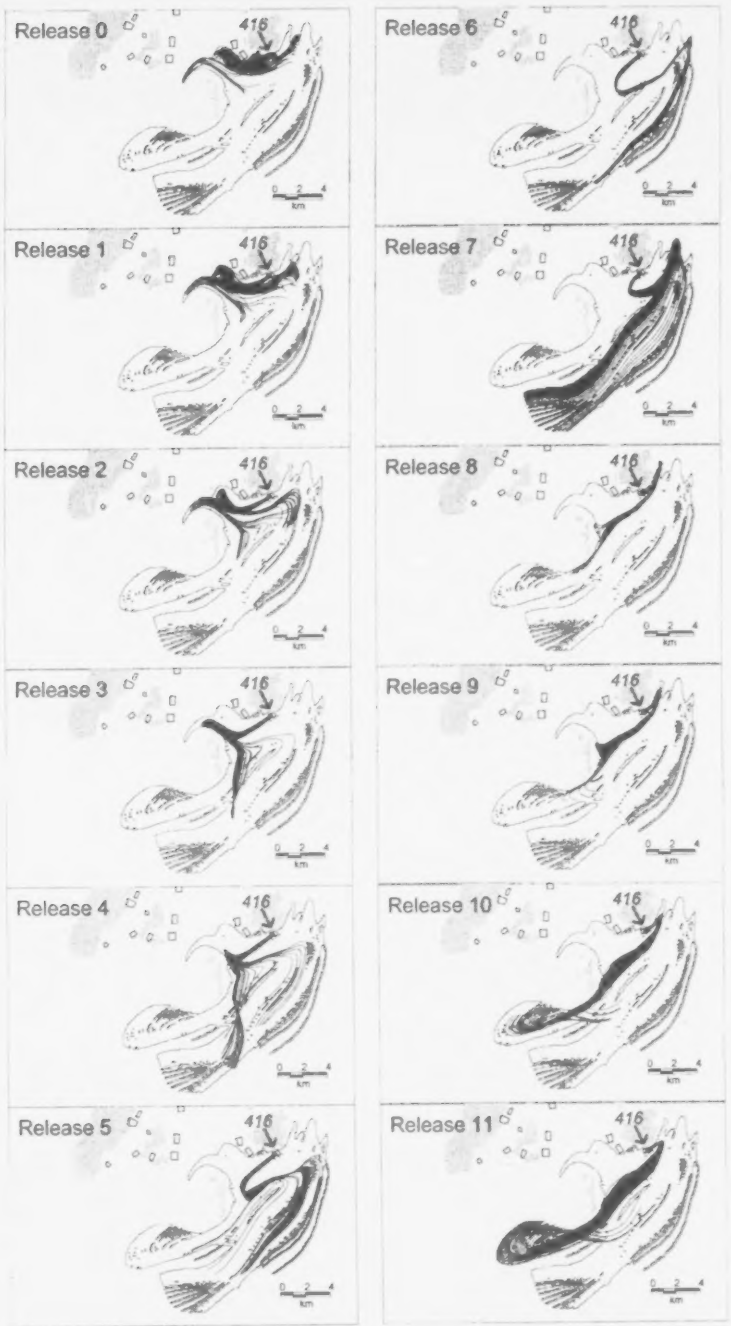

Fig. 13L. Model particle tracks for each hourly release (0 to 11) from farm 416 in Bay Management Area 19. See caption for Fig. 13a.

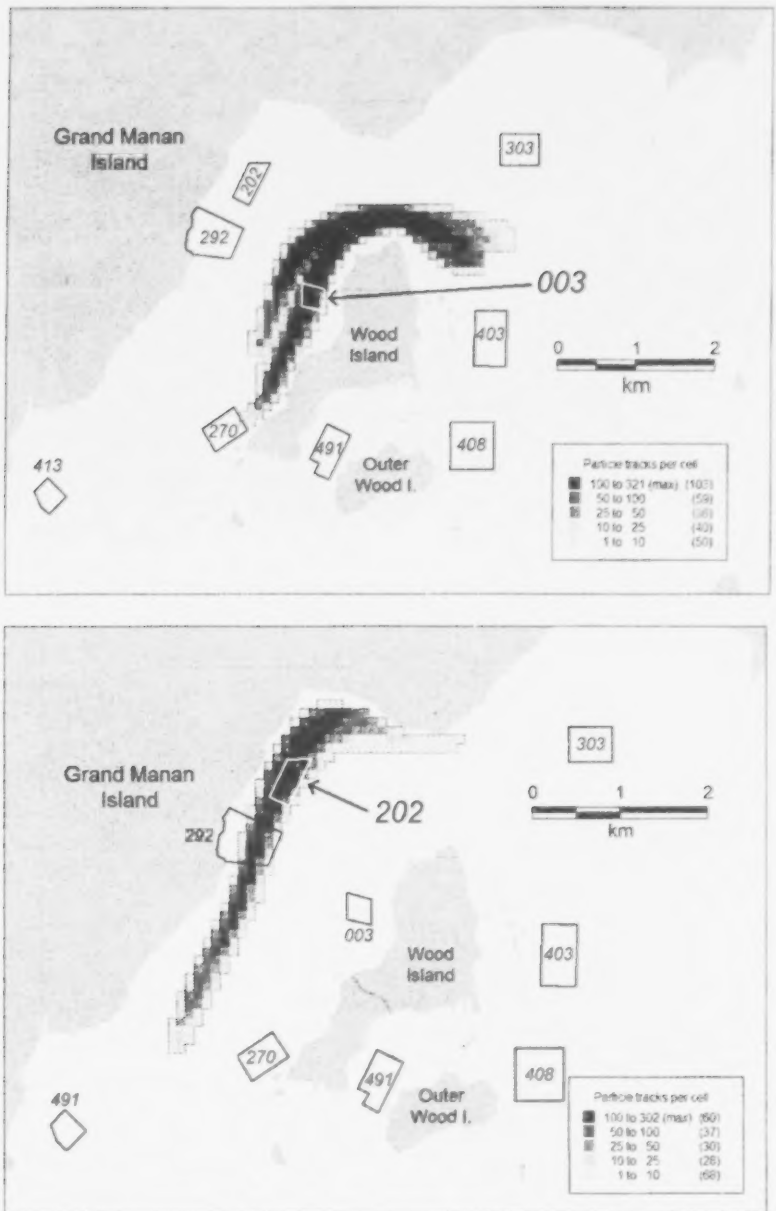

Fig. 14a. Model-derived tidal excursion areas of farms 003 and 202 in BMA 20. The shading represents the number of model-derived particle tracks intersecting each 100 m × 100 m square cell (see map legend). Thirty-six particles were released from a 200 m × 200 m grid located at the farm site, at hourly intervals over a 12-h period (total of 432 particles released from each farm). Each particle was tracked for one tidal excursion (12.42 h) or until it stopped upon hitting the shore, whichever came first. Farm sites are shown as small white polygons, with their site identification numbers. Numbers in parentheses in the legend are the numbers of 100 m × 100 m cells within each range.

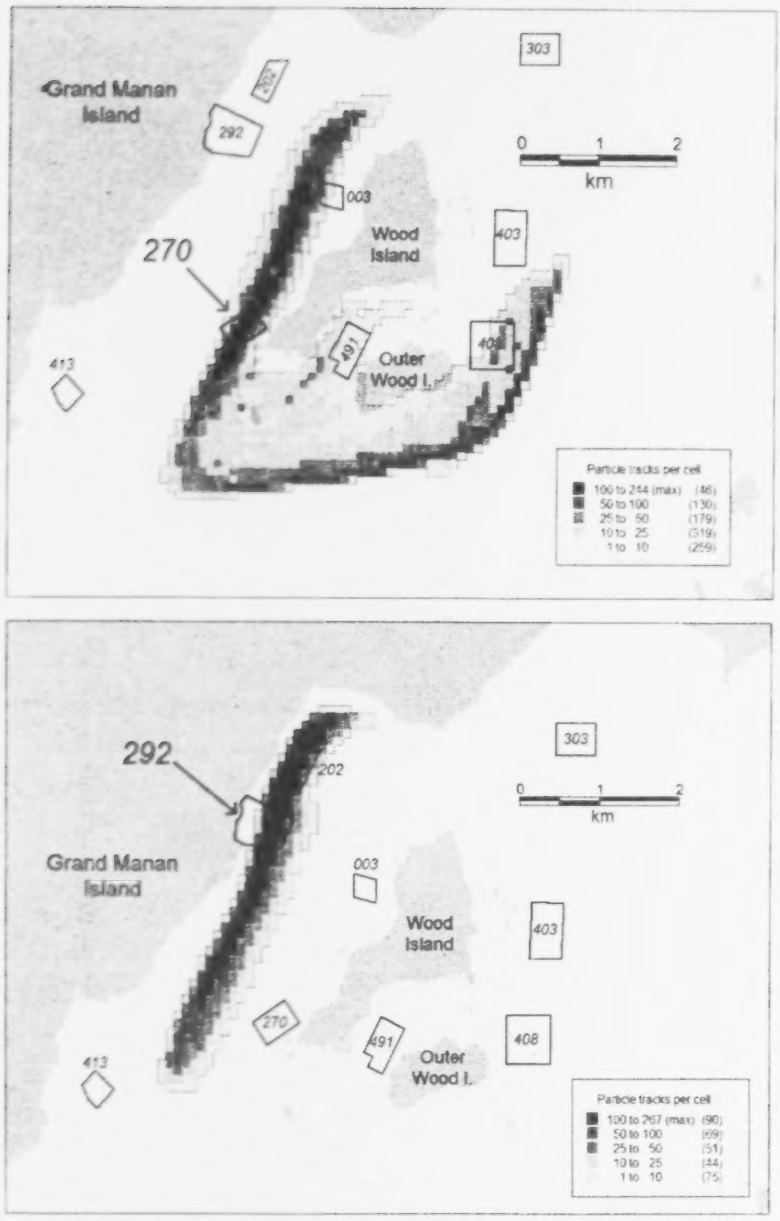

Fig. 14b. Model-derived tidal excursion areas of farms 270 and 292 in BMA 20. See caption for Fig. 14a.

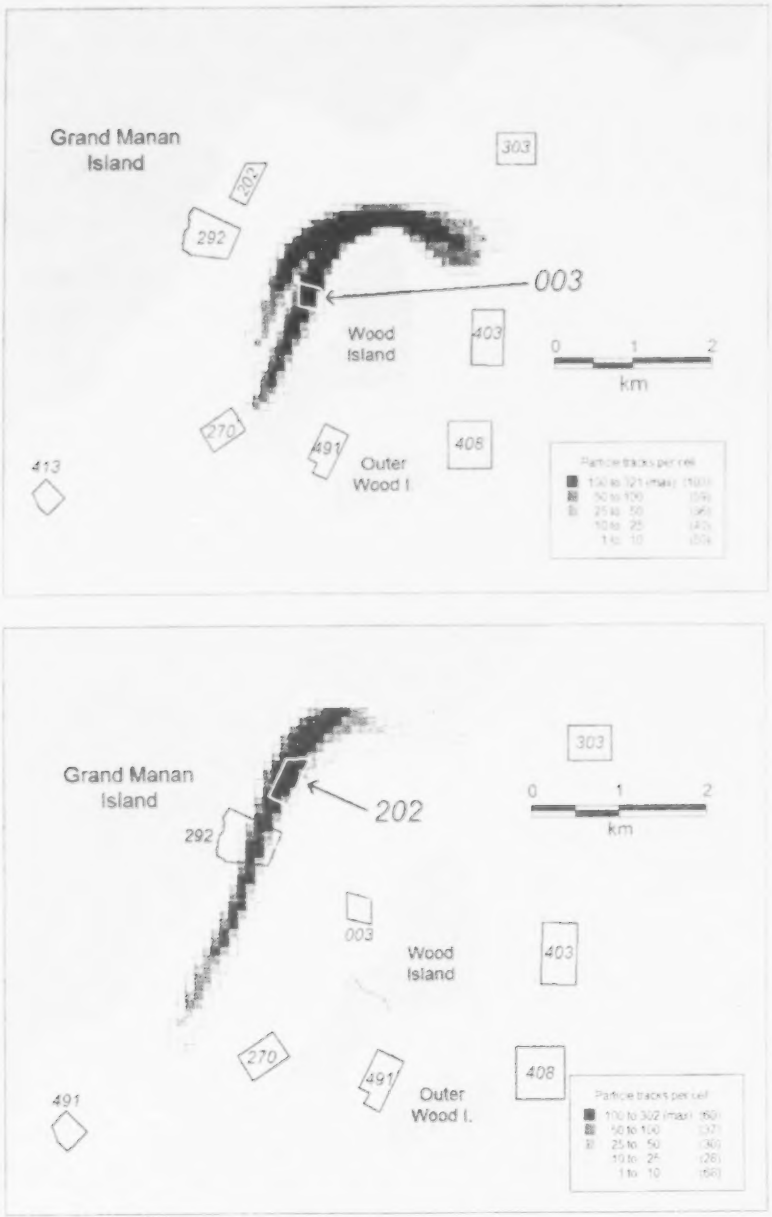

Fig. 14a. Model-derived tidal excursion areas of farms 003 and 202 in BMA 20. The shading represents the number of model-derived particle tracks intersecting each 100 m × 100 m square cell (see map legend). Thirty-six particles were released from a 200 m × 200 m grid located at the farm site, at hourly intervals over a 12-h period (total of 432 particles released from each farm). Each particle was tracked for one tidal excursion (12.42 h) or until it stopped upon hitting the shore, whichever came first. Farm sites are shown as small white polygons, with their site identification numbers. Numbers in parentheses in the legend are the numbers of 100 m × 100 m cells within each range.

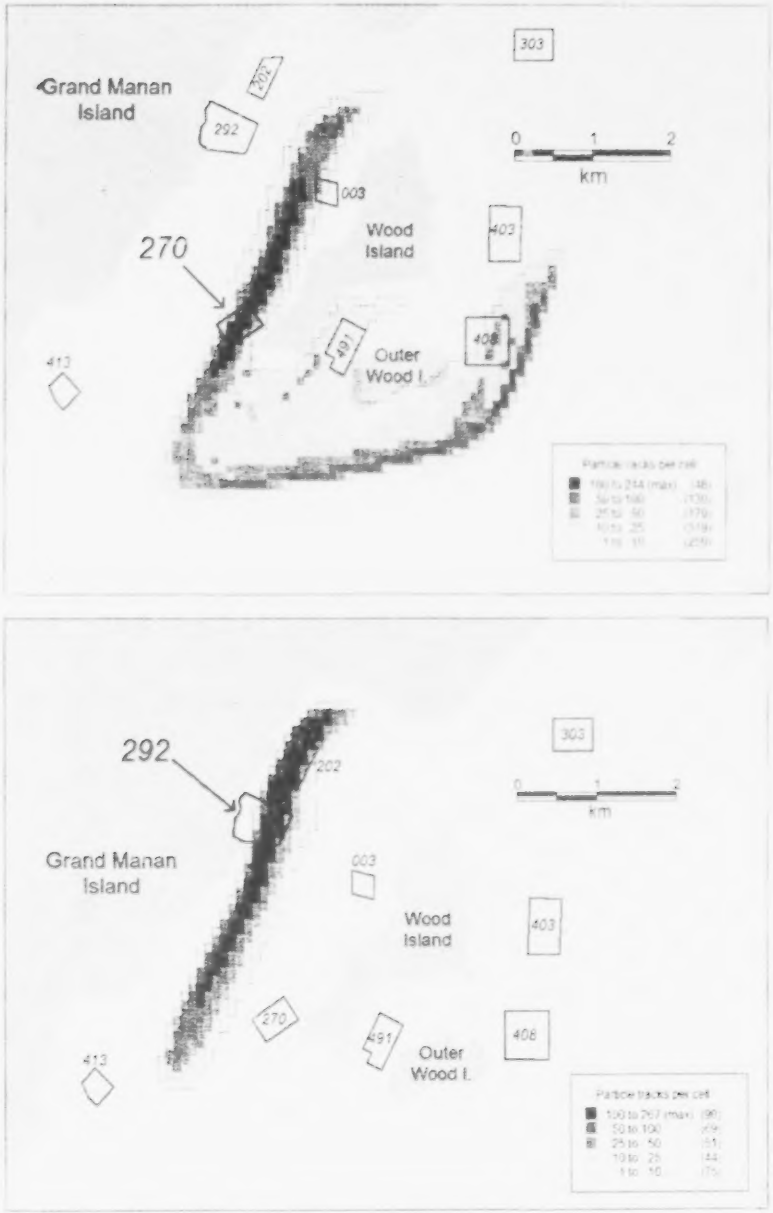

Fig. 14b. Model-derived tidal excursion areas of farms 270 and 292 in BMA 20. See caption for Fig. 14a.

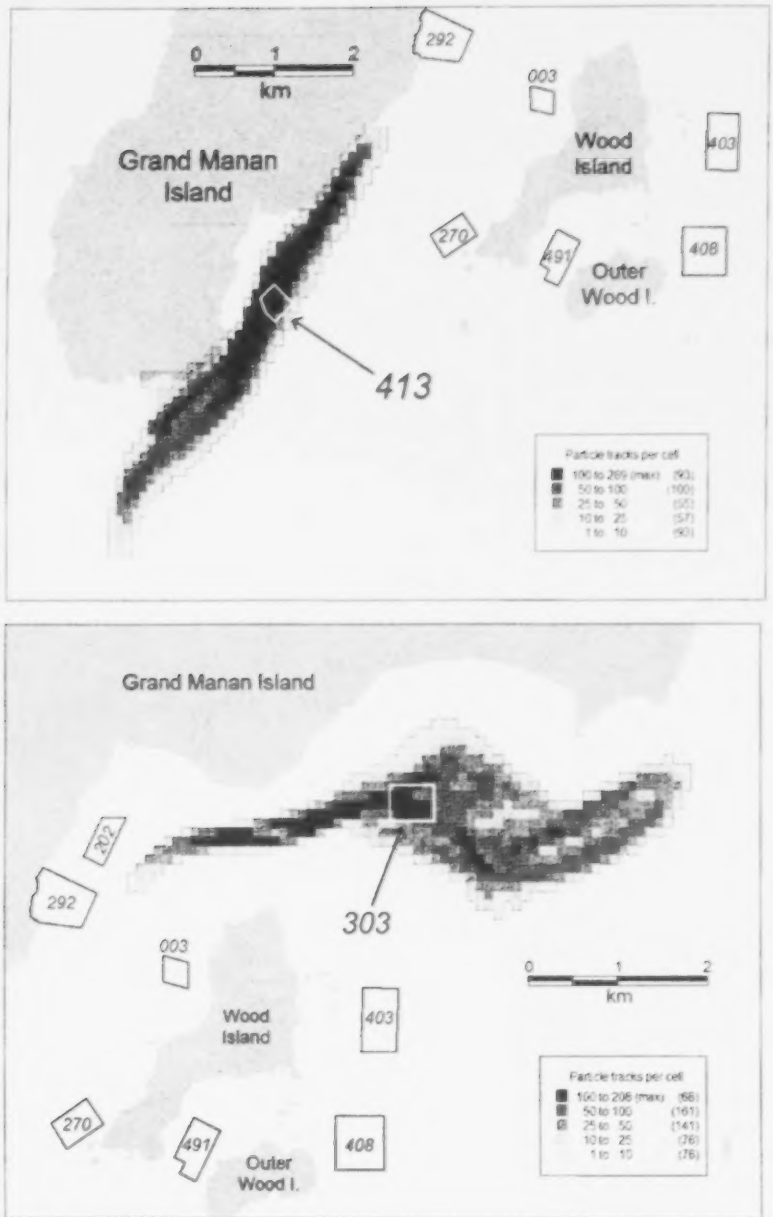

Fig. 14c. Model-derived tidal excursion areas of farm 413 in BMA 20 and farm 303 in BMA 21. See caption for Fig. 14a.

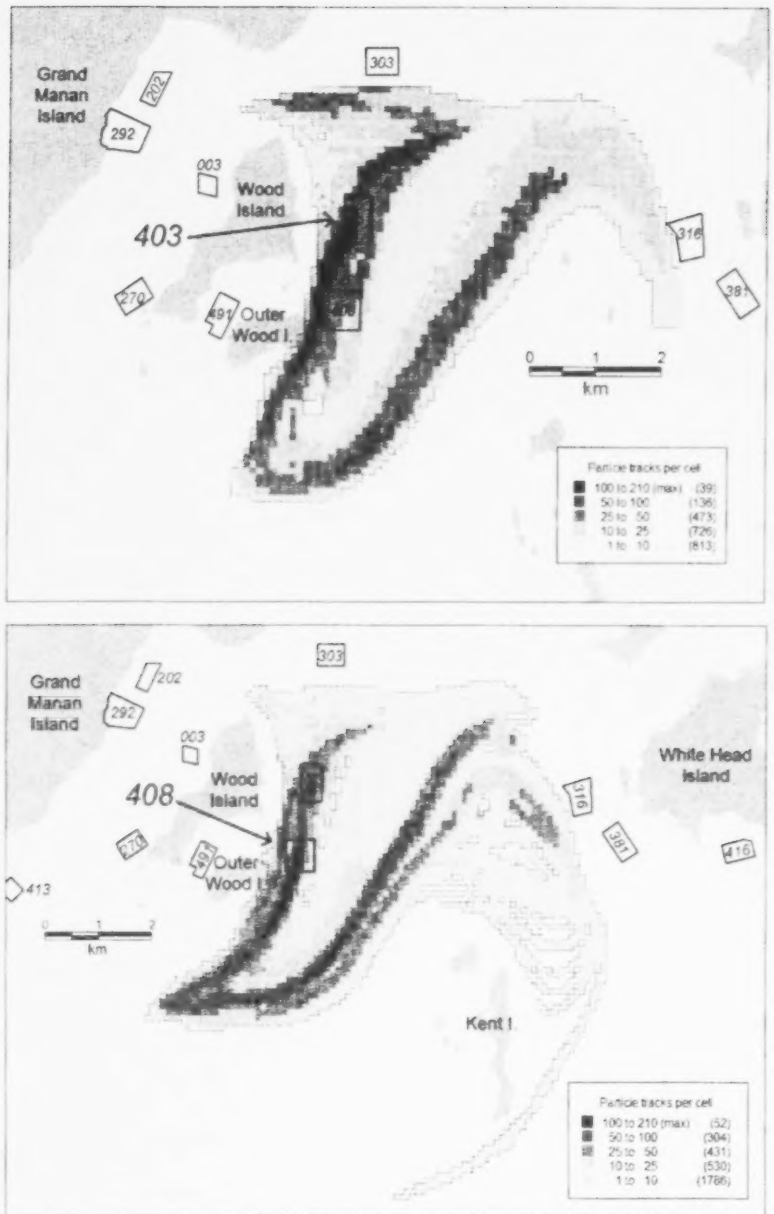

Fig. 14d. Model-derived tidal excursion areas of farms 403 and 408 in BMA 21. See caption for Fig. 14a.

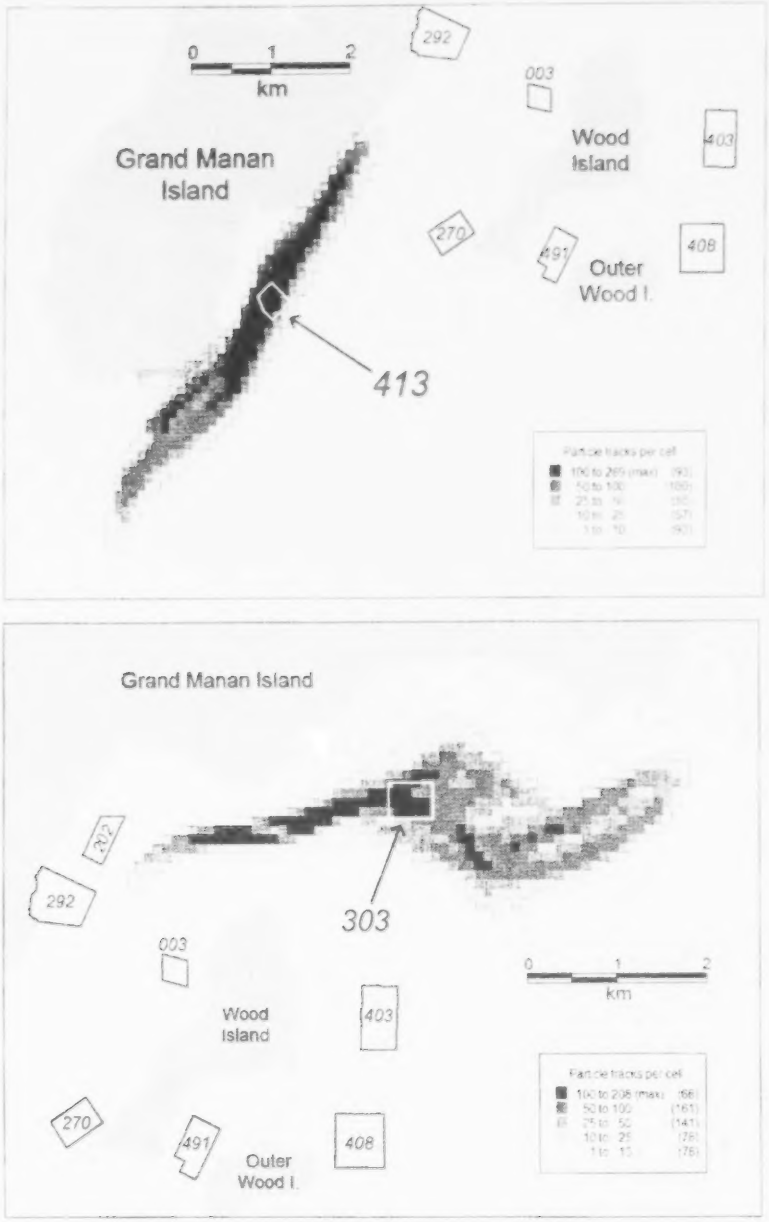

Fig. 14c. Model-derived tidal excursion areas of farm 413 in BMA 20 and farm 303 in BMA 21. See caption for Fig. 14a.

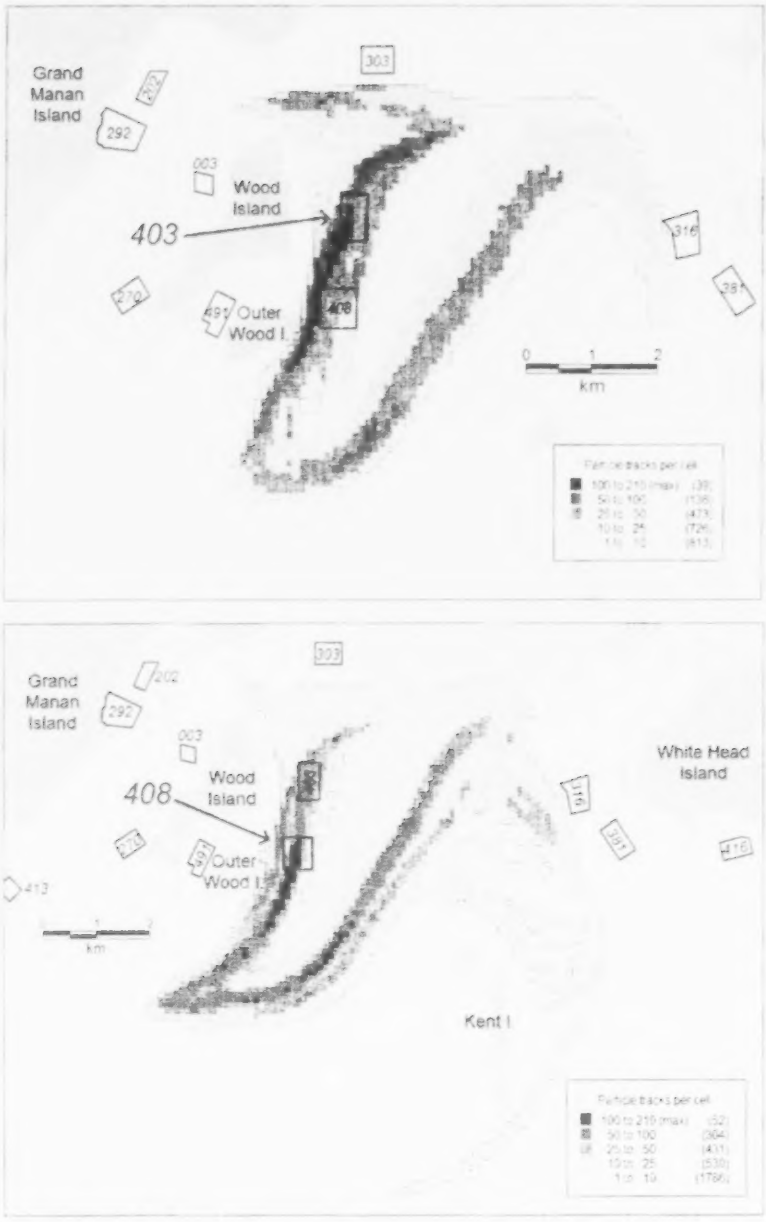

Fig. 14d. Model-derived tidal excursion areas of farms 403 and 408 in BMA 21. See caption for Fig. 14a.

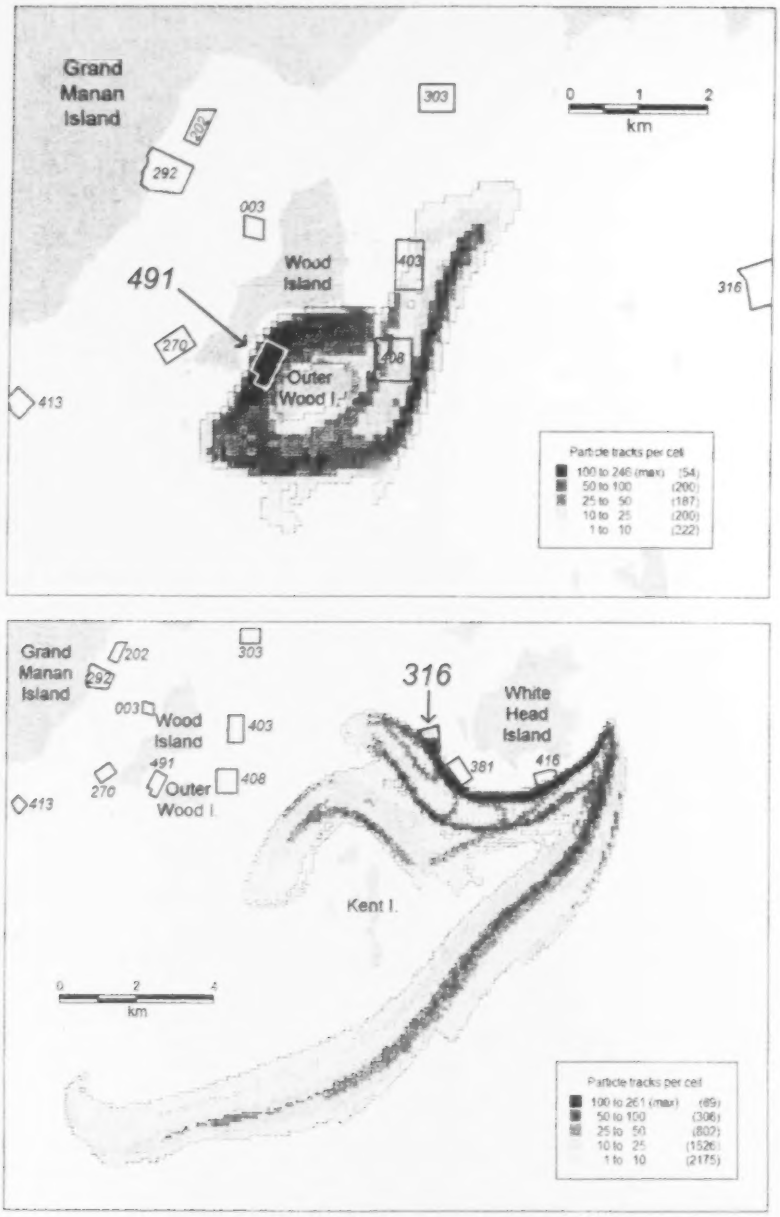

Fig. 14e. Model-derived tidal excursion areas of farm 491 in BMA 21 and farm 316 in BMA 19. See caption for Fig. 14a.

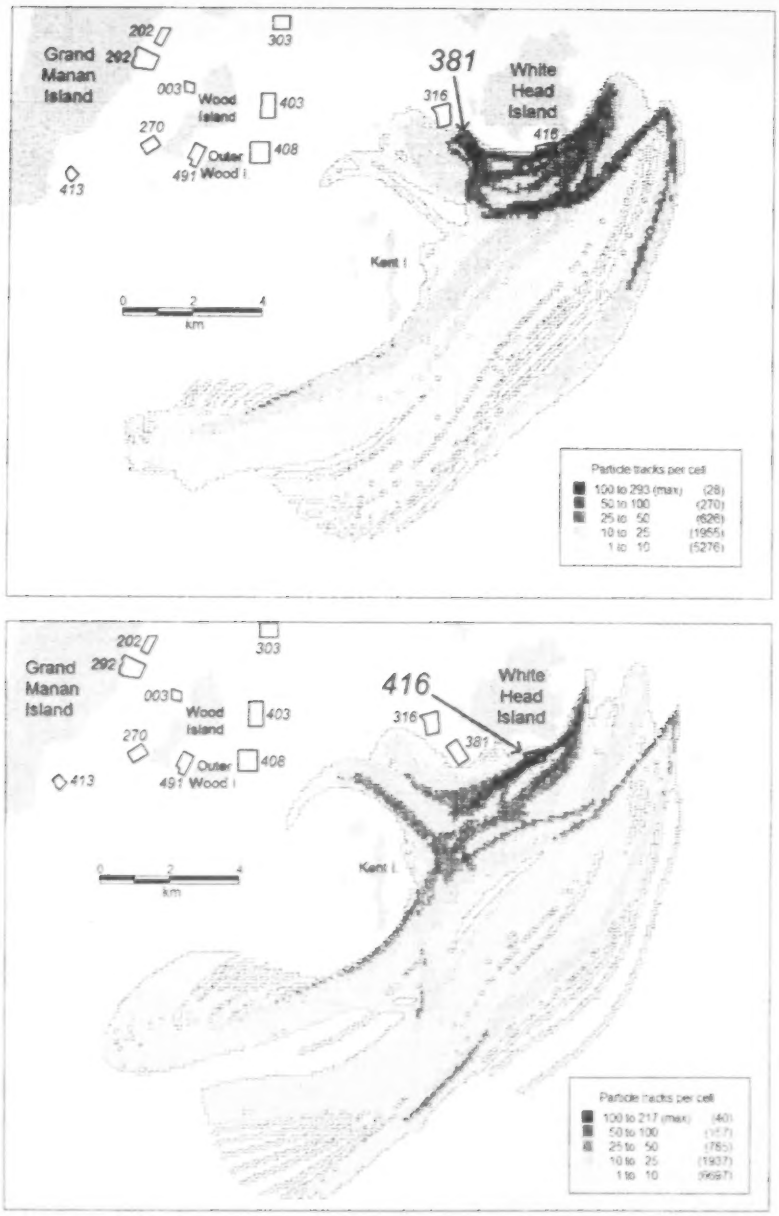

Fig. 14f. Model-derived tidal excursion areas of farms 381 and 416 in BMA 19. See caption for Fig. 14a.

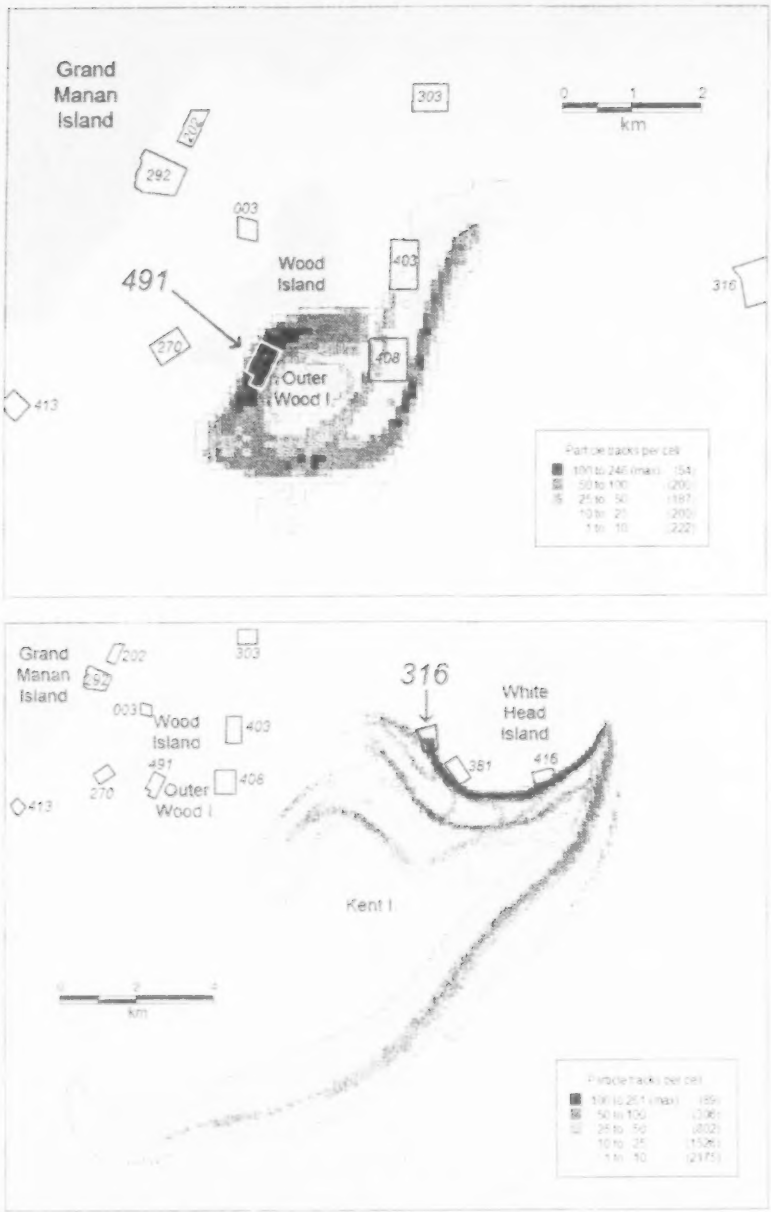

Fig. 14e. Model-derived tidal excursion areas of farm 491 in BMA 21 and farm 316 in BMA 19. See caption for Fig. 14a.

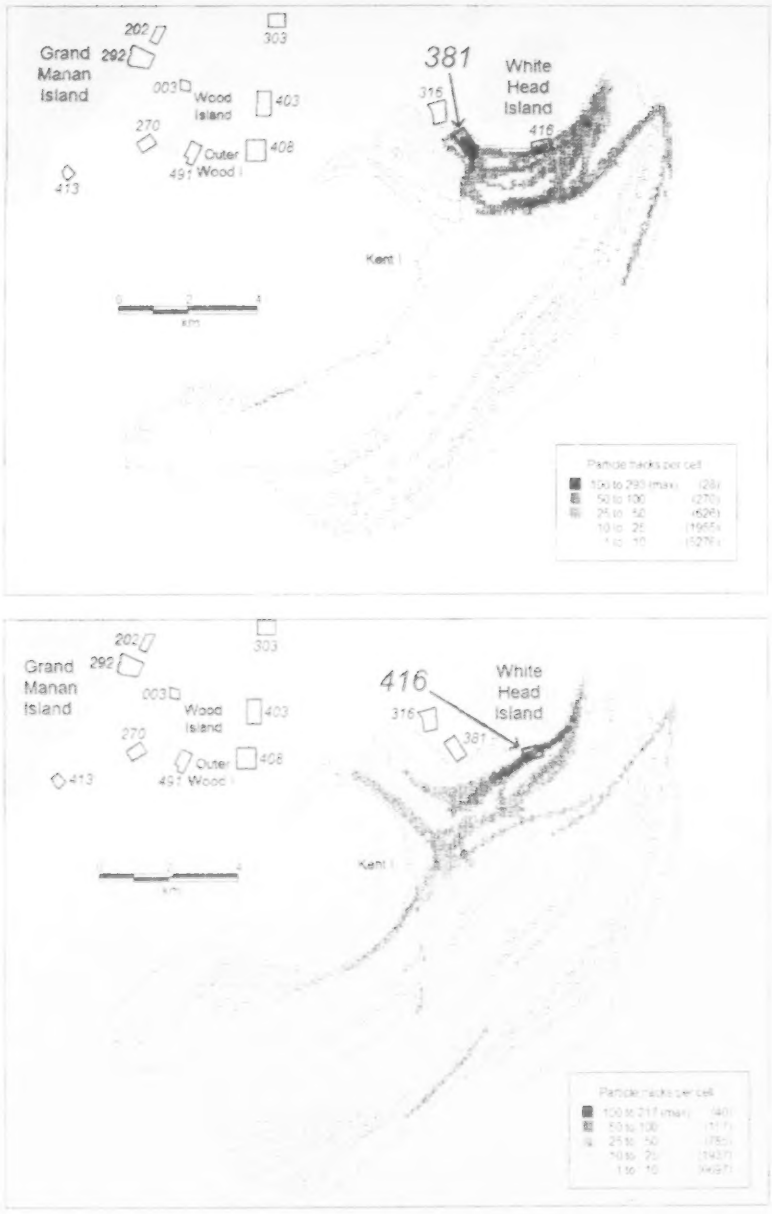

Fig. 14f. Model-derived tidal excursion areas of farms 381 and 416 in BMA 19. See caption for Fig. 14a.

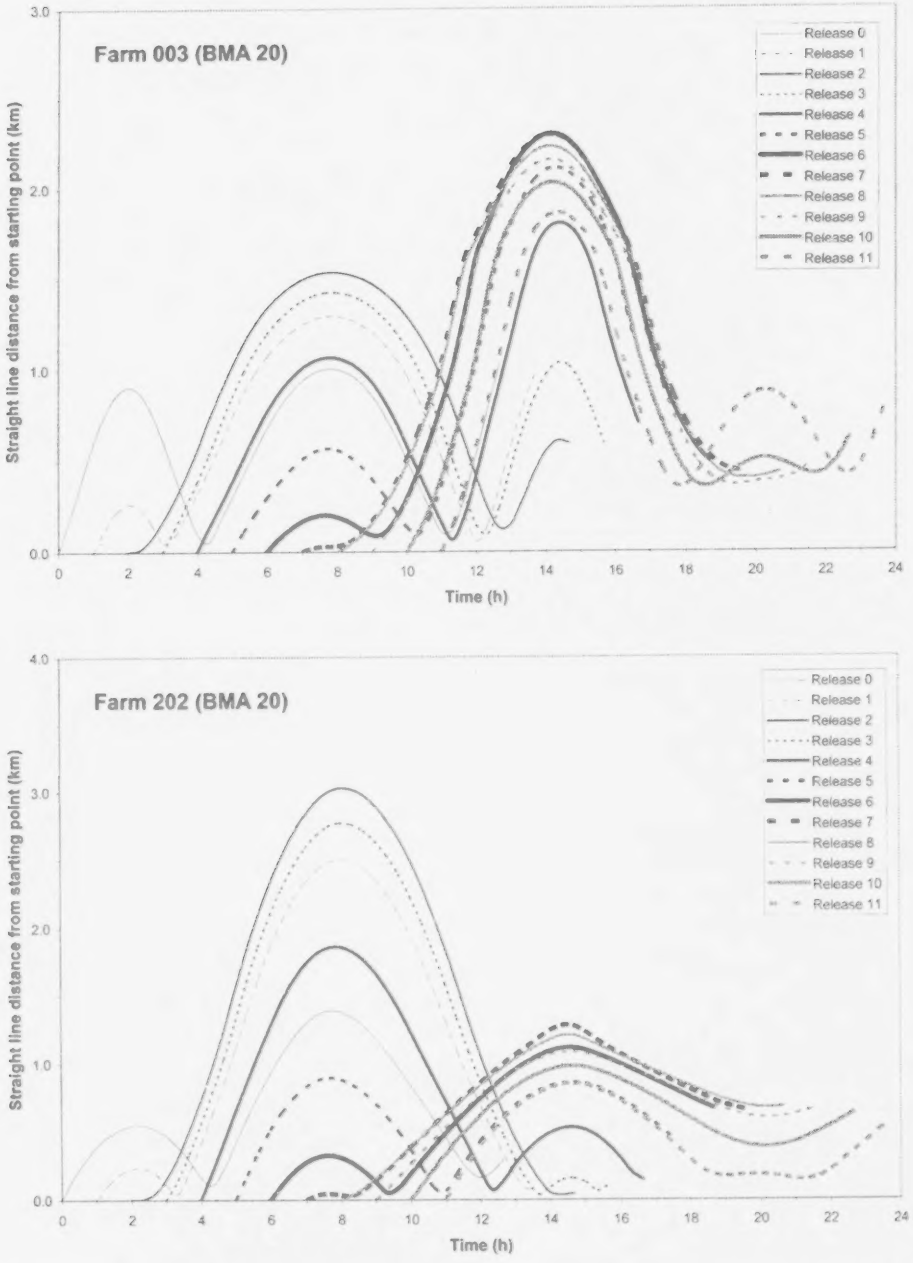

Fig. 15a. Straight line displacement from starting points versus time for model particles released at hourly intervals over a 12-h period (releases 0 to 11) from farms 003 and 202 in BMA 20. Each line represents the average displacements (calculated every 20 min) of 36 particles released from a 200 m × 200 m grid located at the farm site and tracked for one tidal excursion (12.4 h). Particle tracks were ended if they hit the shore, so the later segments of some lines may represent fewer than 36 particles.

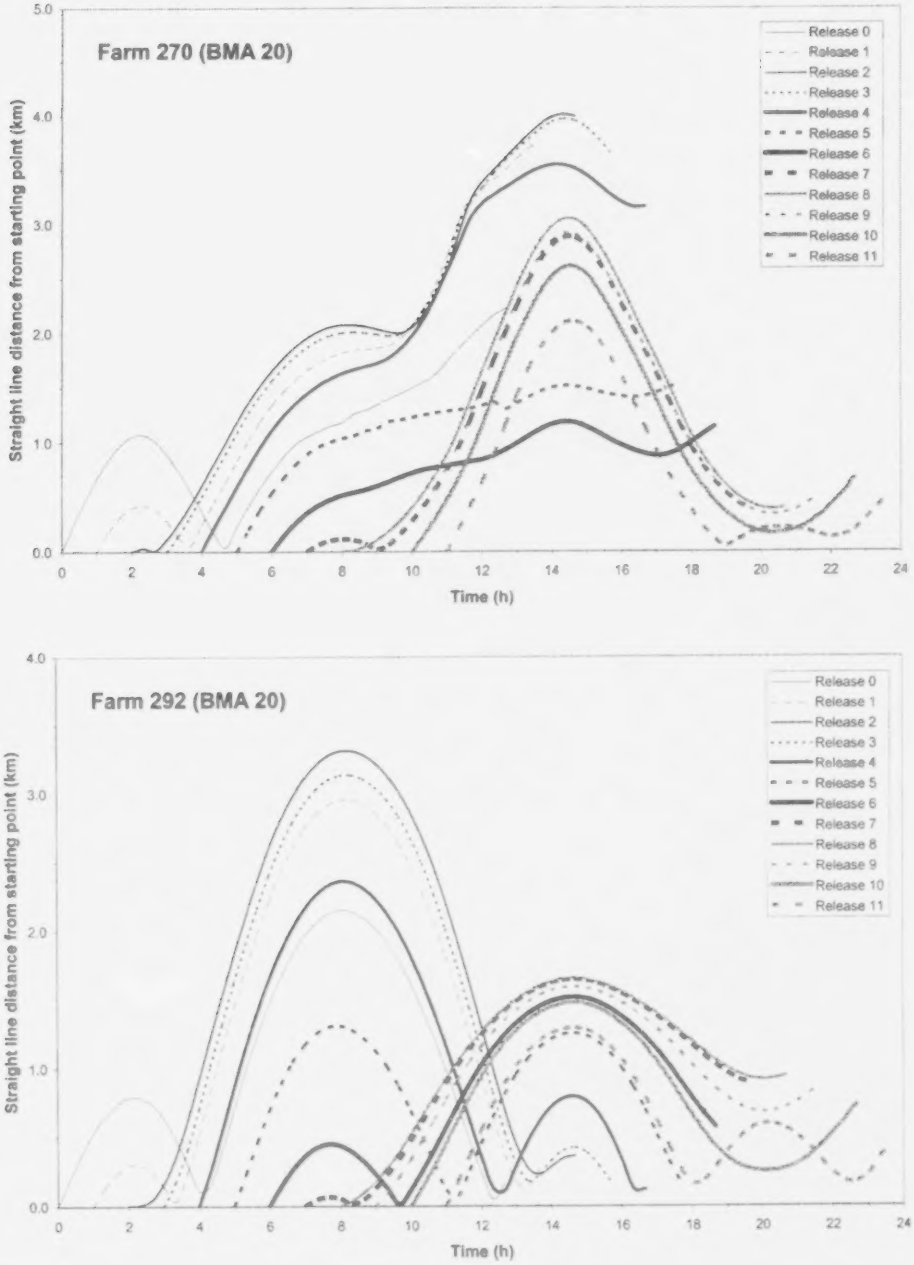

Fig. 15b. Straight line displacement from starting points versus time for model particles released at hourly intervals over a 12-h period (releases 0 to 11) from farms 270 and 292 in BMA 20. See caption for Fig. 15a.

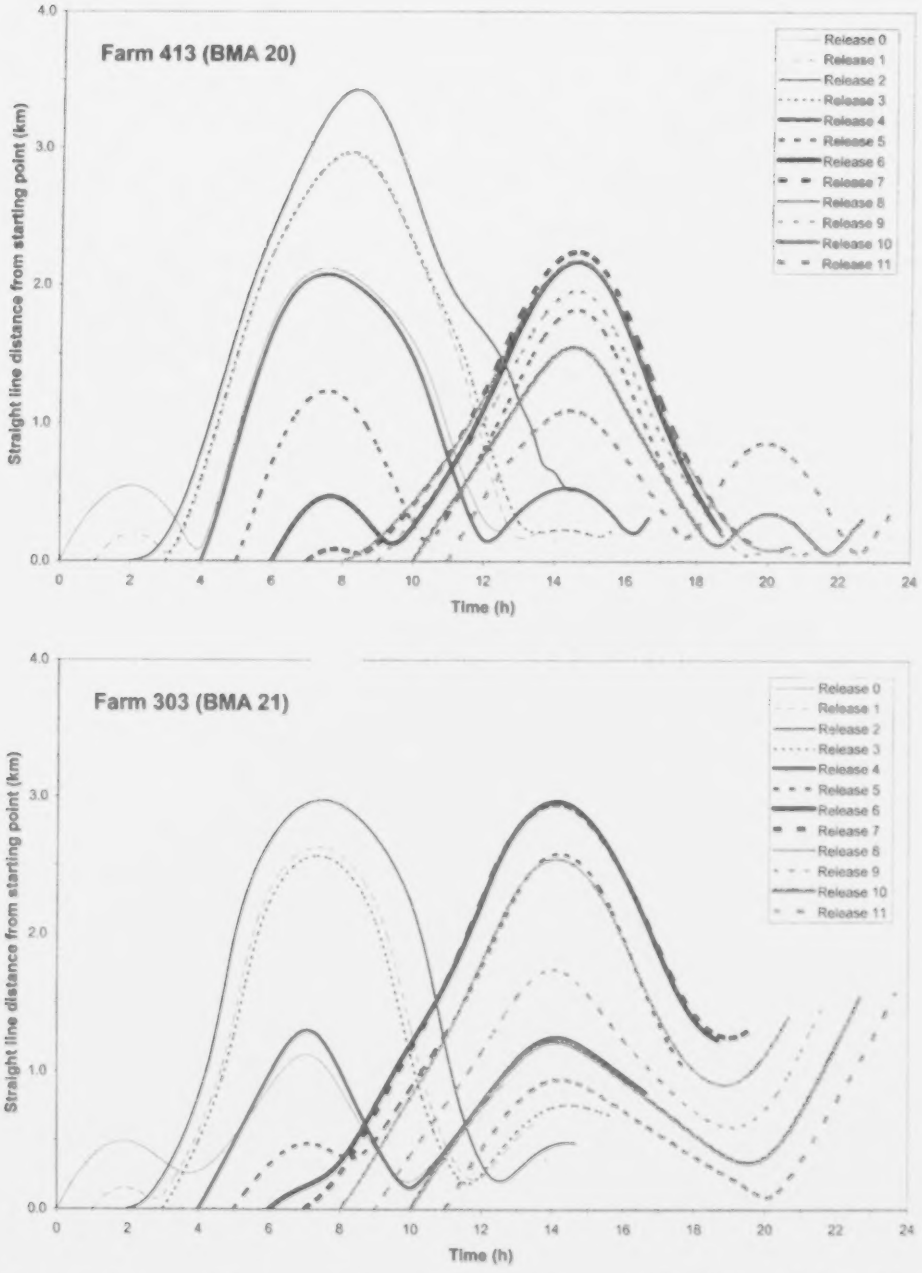

Fig. 15c. Straight line displacement from starting points versus time for model particles released at hourly intervals over a 12-h period (releases 0 to 11) from farm 413 in BMA 20 and farm 303 in BMA 21. See caption for Fig. 15a.

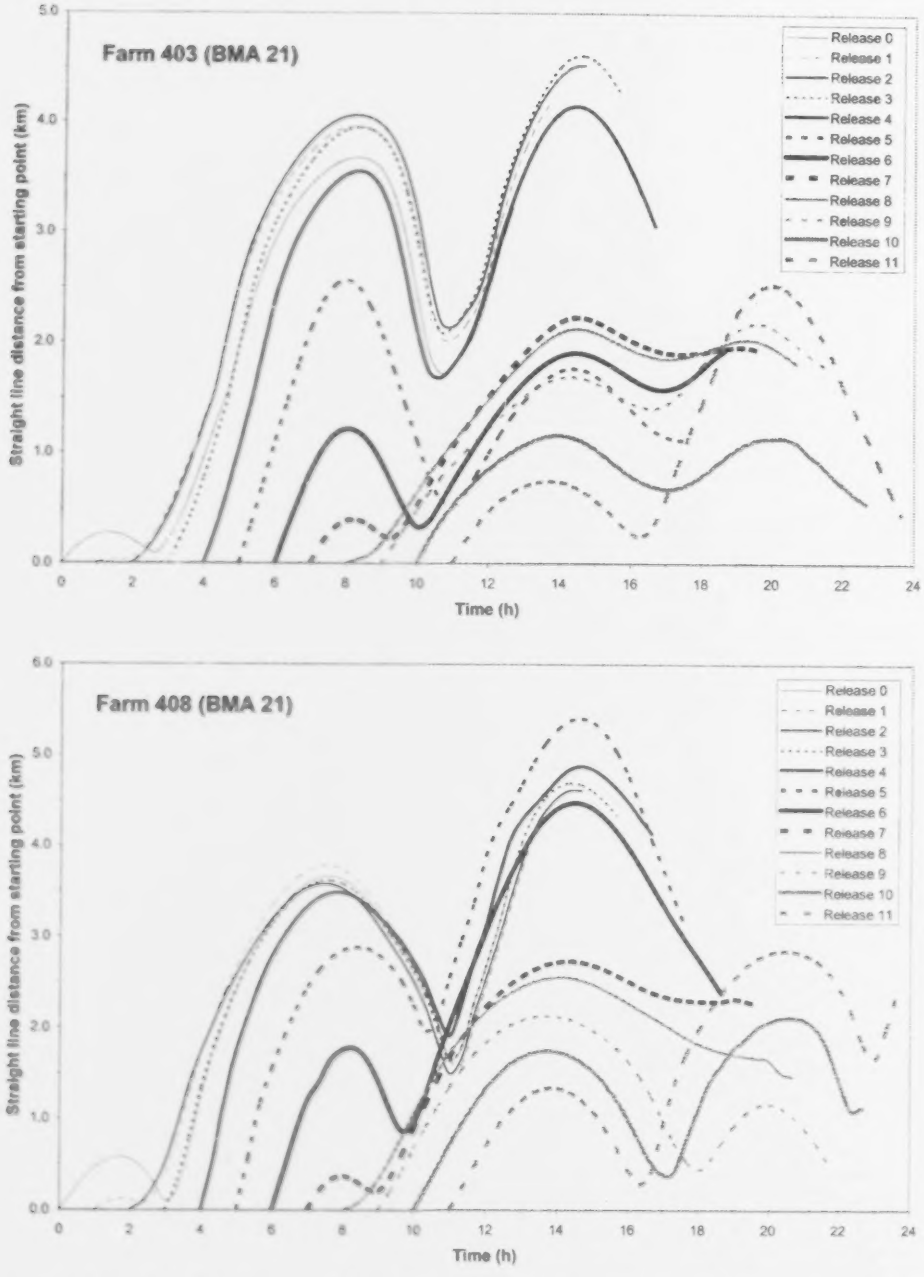

Fig. 15d. Straight line displacement from starting points versus time for model particles released at hourly intervals over a 12-h period (releases 0 to 11) from farms 403 and 408 in BMA 21. See caption for Fig. 15a.

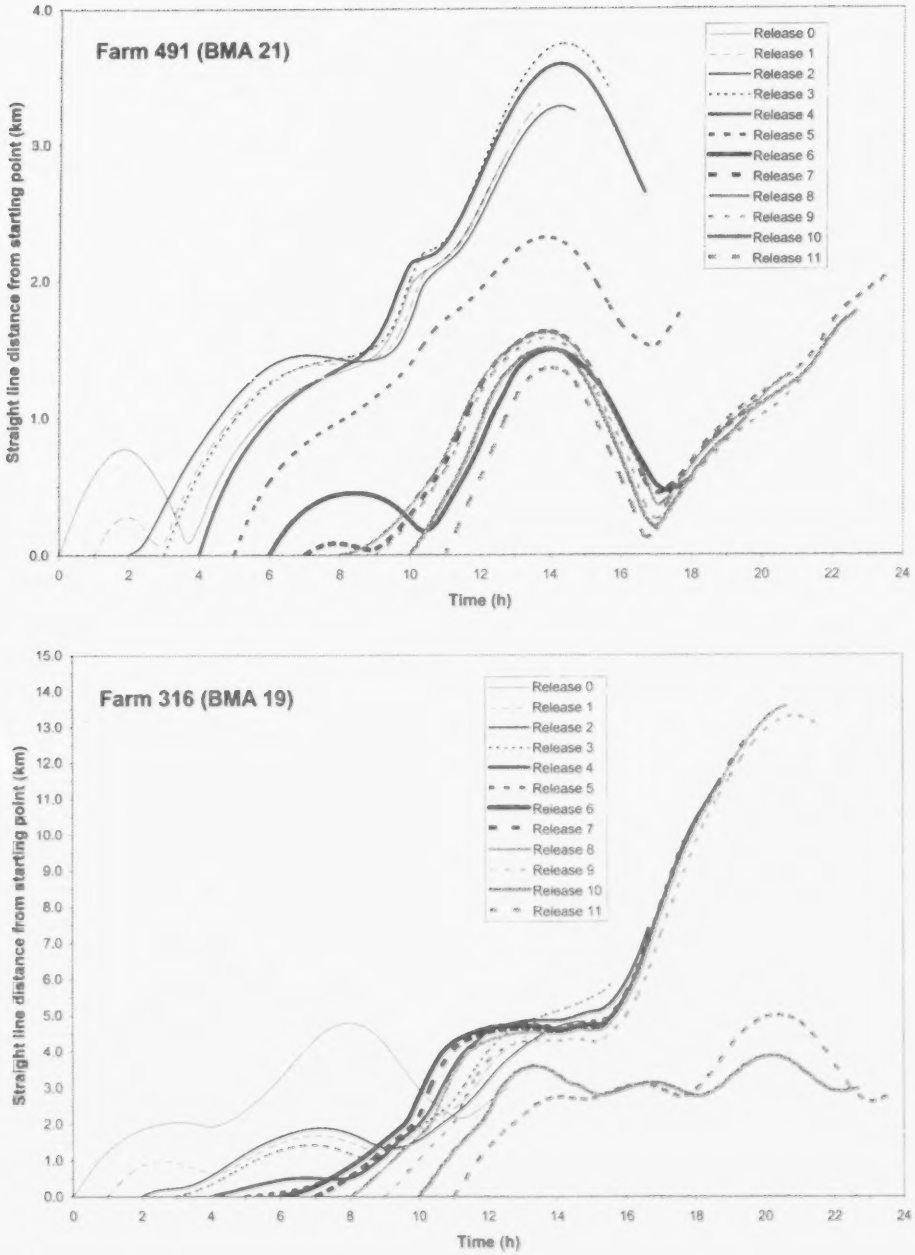

Fig. 15e. Straight line displacement from starting points versus time for model particles released at hourly intervals over a 12-h period (releases 0 to 11) from farm 491 in BMA 21 and farm 316 in BMA 19. See caption for Fig. 15a.

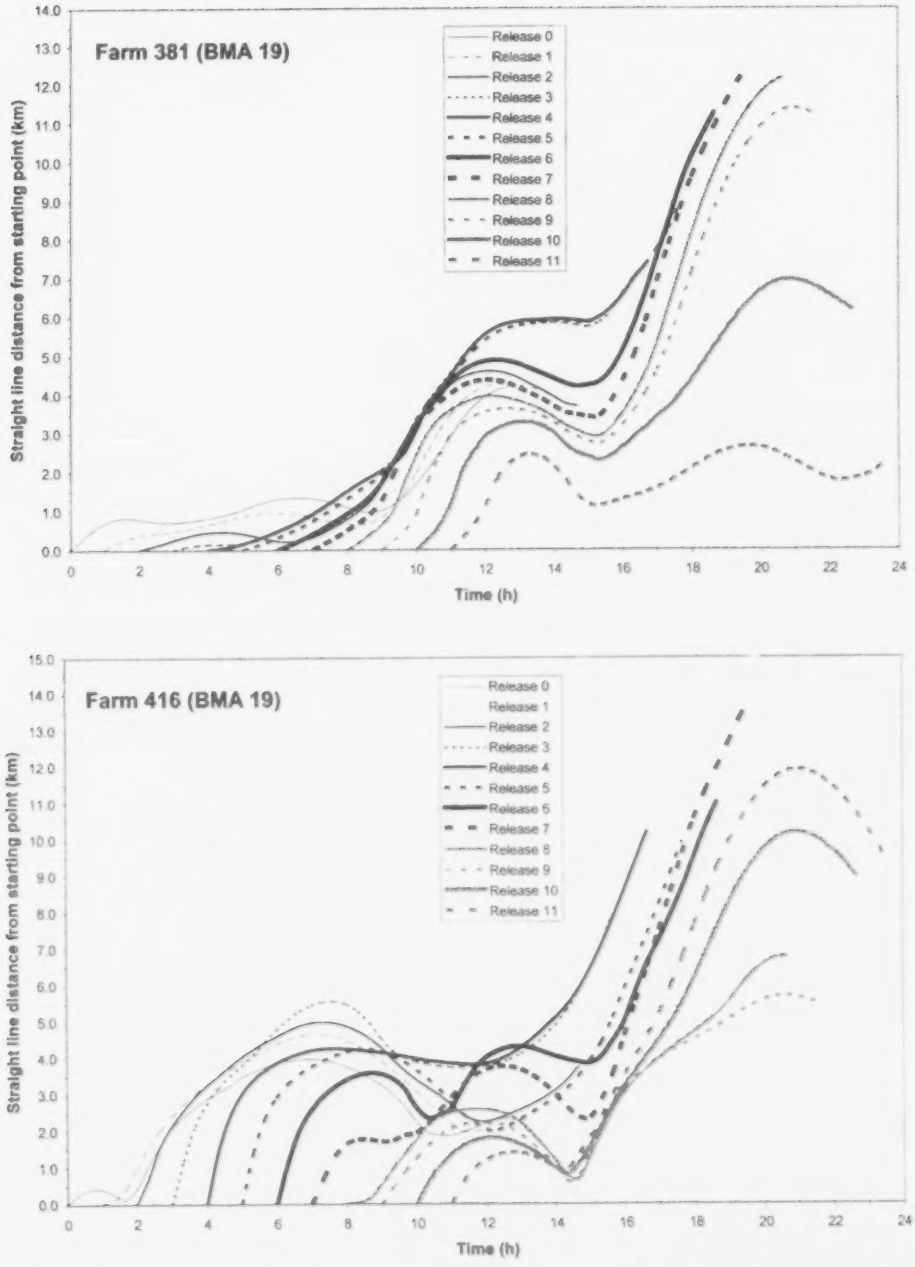

Fig. 15f. Straight line displacement from starting points versus time for model particles released at hourly intervals over a 12-h period (releases 0 to 11) from farms 381 and 416 in BMA 19. See caption for Fig. 15a.

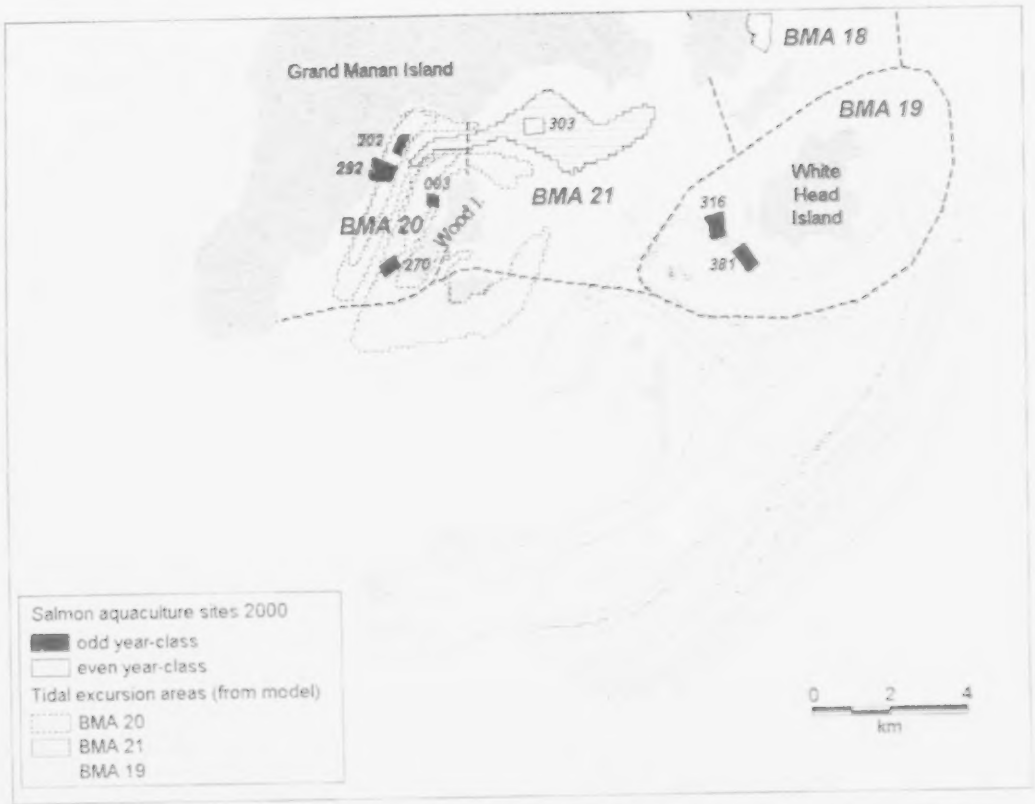

Fig. 16. Salmon farms in the southern Grand Manan Island area in 2000, with model-derived tidal excursion areas (see text for details). BMA = Bay Management Area. Site identification numbers are shown beside the farm sites.

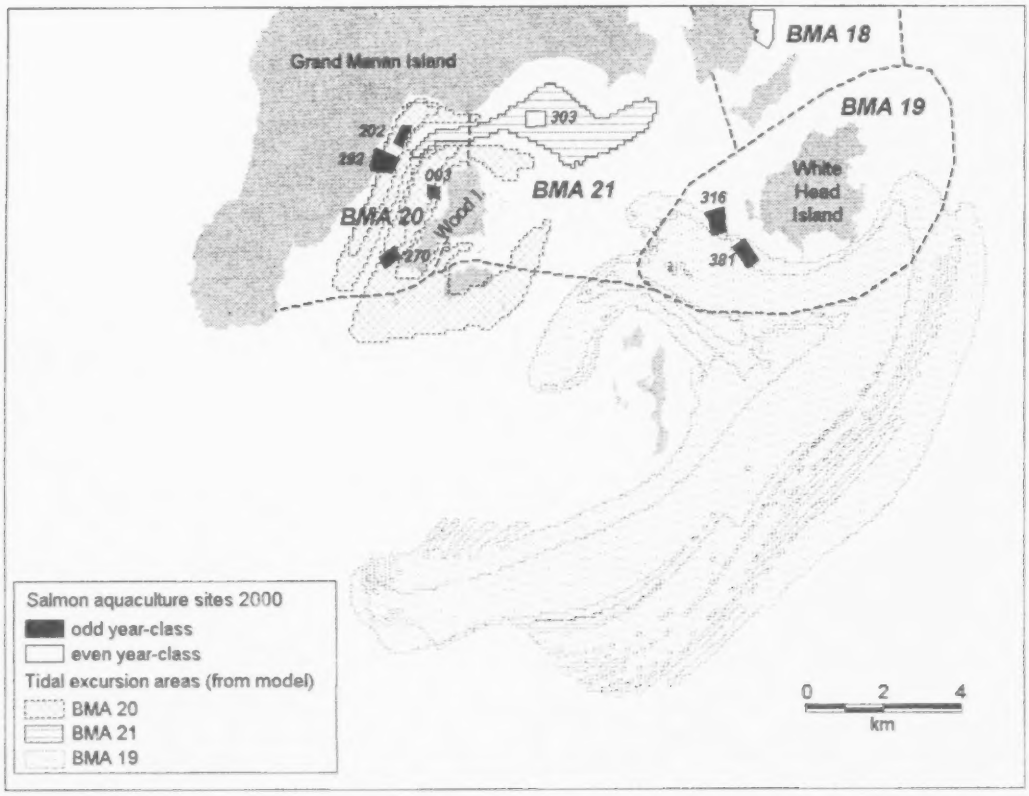

Fig. 16. Salmon farms in the southern Grand Manan Island area in 2000, with model-derived tidal excursion areas (see text for details). BMA = Bay Management Area. Site identification numbers are shown beside the farm sites.

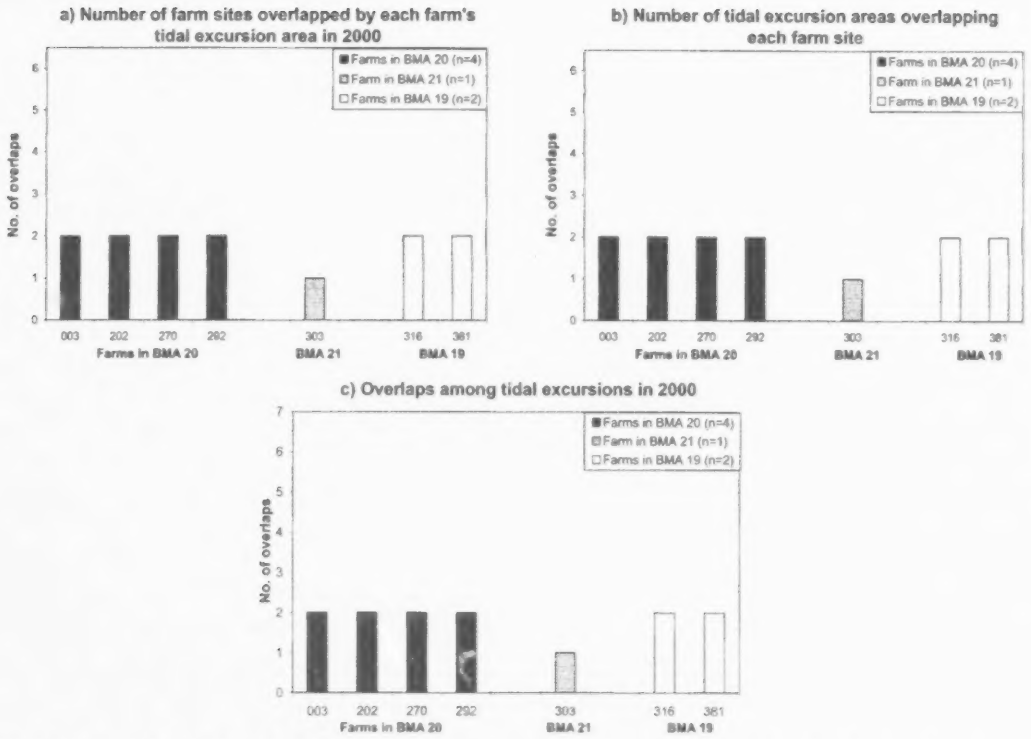

Fig. 17. Overlaps of model-derived tidal excursion areas and farm sites in the southern Grand Manan Island area in 2000: a) number of farm sites overlapped by each farm's tidal excursion area; b) number of tidal excursion areas overlapping each farm site; c) number of overlaps among tidal excursion areas. The numbers include overlaps with the originating farm. The maximum possible number of overlaps is 7. The three figures show identical values.

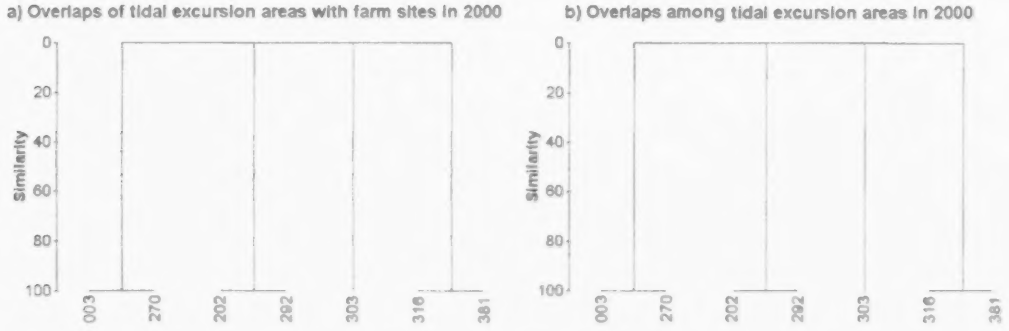

Fig. 18. Cluster analyses using Bray-Curtis similarity coefficients calculated on the presence or absence of overlaps using model-derived tidal excursion areas, for finfish farms in the southern Grand Manan Island area in 2000: a) overlaps of tidal excursion areas with farm sites; b) overlaps among tidal excursion areas. The two figures show identical values.

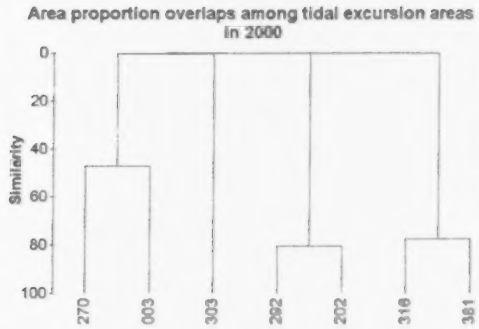

Fig. 19. Cluster analysis using Bray-Curtis similarity coefficients calculated on the areal extent of overlaps among model-derived tidal excursion areas for finfish farms in the southern Grand Manan Island area in 2000. The coefficients were calculated on the areal proportion of the originating farm's tidal excursion area which overlapped the tidal excursion areas of farms operating in the southern Grand Manan area.

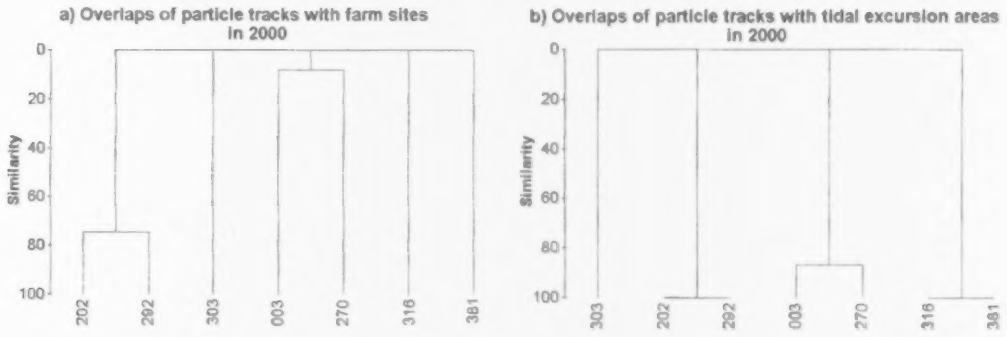

Fig. 20. Cluster analyses using Bray-Curtis similarity coefficients calculated on the number of model-derived particle tracks released from finfish farm sites in the southern Grand Manan Island area in 2000, which overlap with: a) farm sites; b) tidal excursion areas.

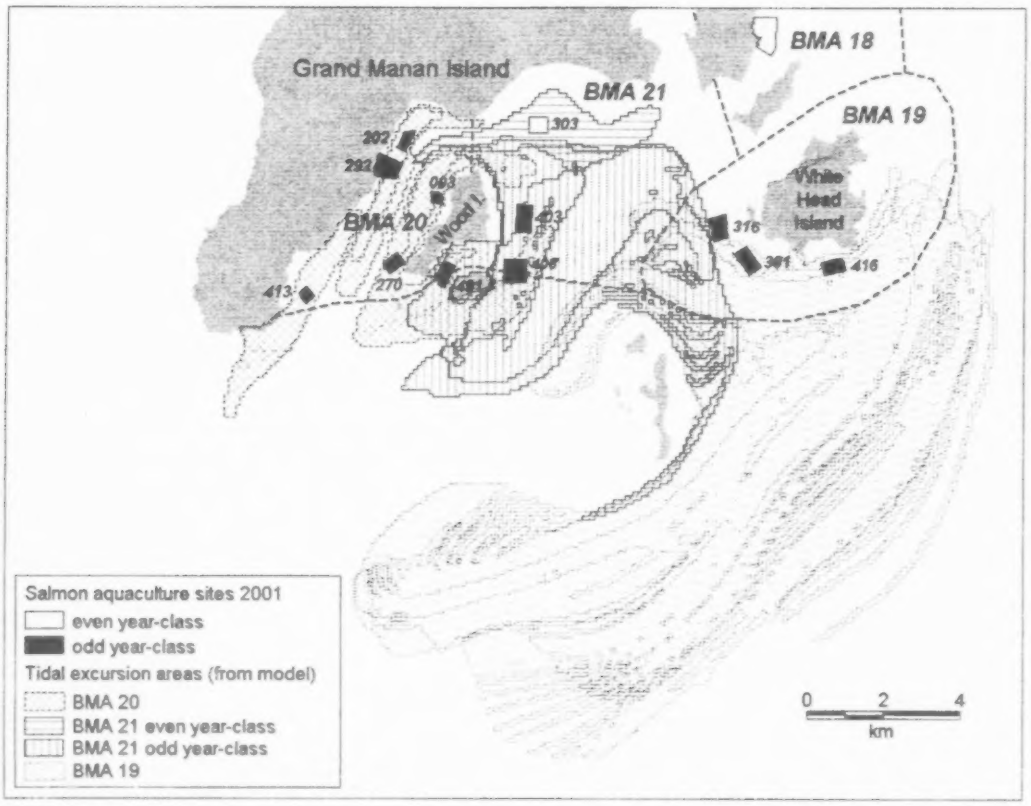

Fig. 21. Licensed salmon farms in the southern Grand Manan Island area in 2001, with model-derived tidal excursion areas (see text for details). BMA = Bay Management Area. Site identification numbers are shown beside the farm sites.

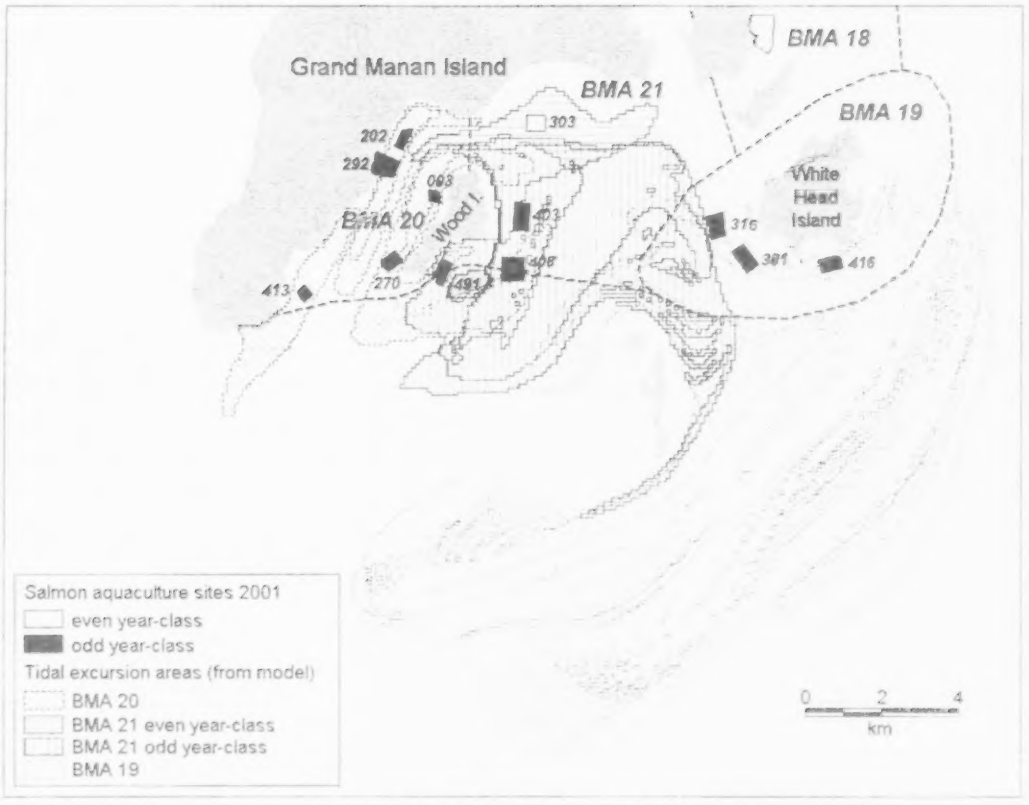

Fig. 21. Licensed salmon farms in the southern Grand Manan Island area in 2001, with model-derived tidal excursion areas (see text for details). BMA = Bay Management Area. Site identification numbers are shown beside the farm sites.

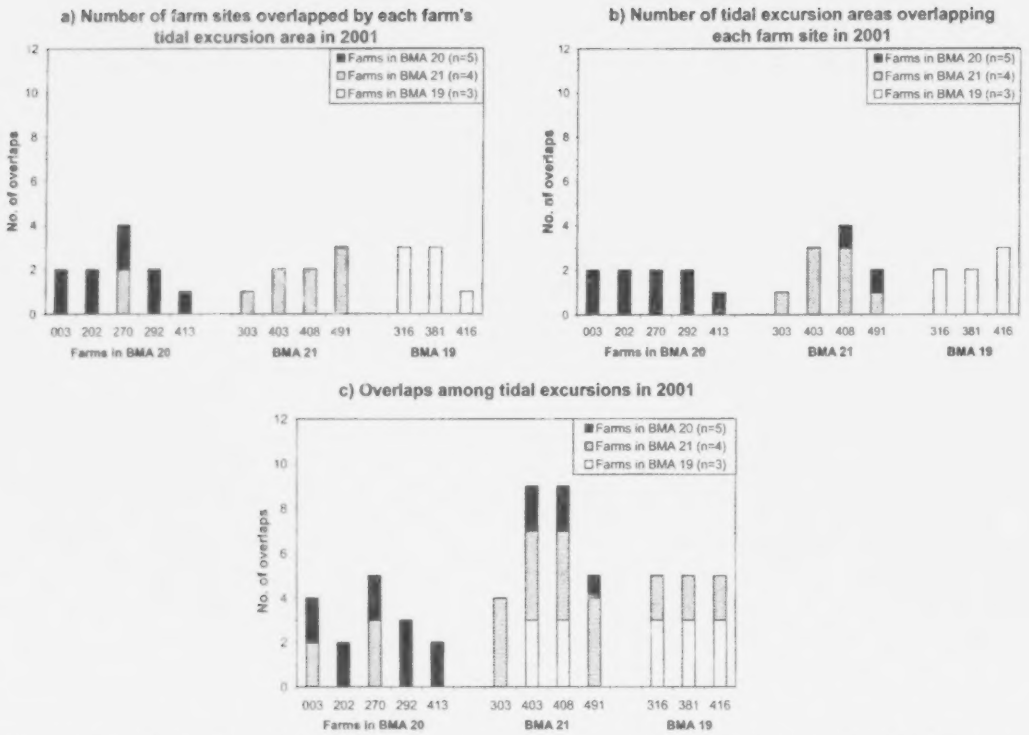
a) Number of farm sites overlapped by each farm's tidal excursion area in 2001
b) Number of tidal excursion areas overlapping each farm site in 2001
c) Overlaps among tidal excursions in 2001
Farms in BMA 20 (n=5)
Farms in BMA 21 (n=4)
Farms in BMA 19 (n=3)
No. of overlaps
003 202 270 292 413
303 403 408 491
316 381 416
Farms in BMA 20
BMA 21
BMA 19

Fig. 22. Overlaps of model-derived tidal excursion areas and finfish farm sites in the southern Grand Manan Island area in 2001: a) number of farm sites overlapped by each farm's tidal excursion area; b) number of tidal excursion areas overlapping each farm site; c) number of overlaps among tidal excursion areas. The numbers include overlaps with the originating farm. The maximum possible number of overlaps is 12.

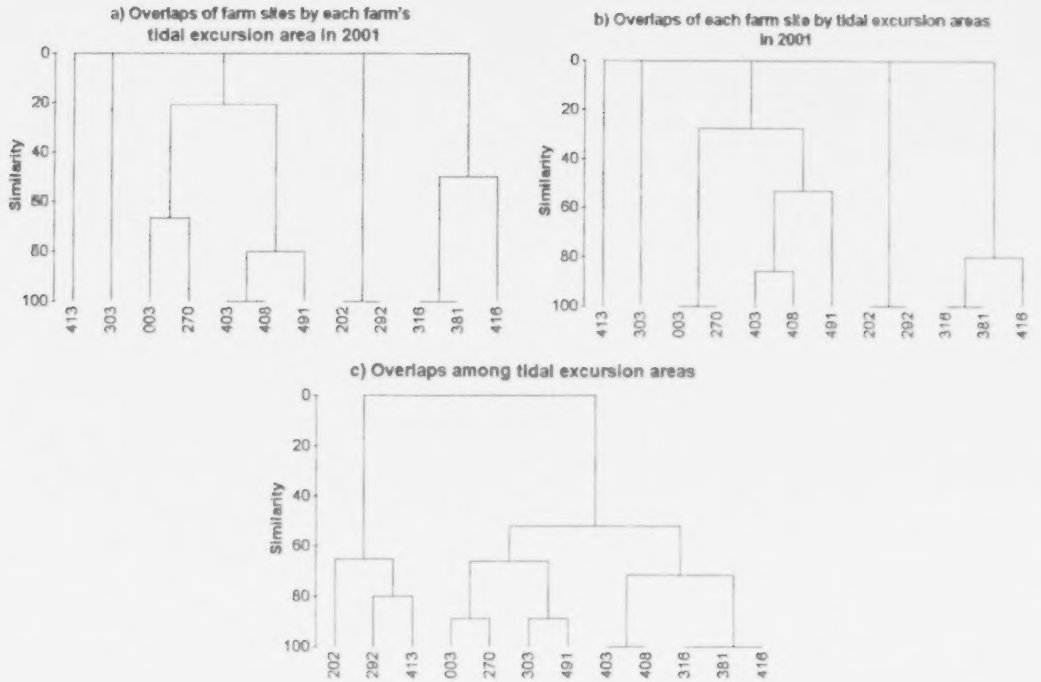

Fig. 23. Cluster analyses using Bray-Curtis similarity coefficients calculated on the presence or absence of overlaps using model-derived tidal excursion areas, for finfish farms in the southern Grand Manan Island area in 2001: a) overlaps of farm sites by each farm's tidal excursion area (x-axis lists the farms from which the tidal excursion areas originated); b) overlaps of each farm site by tidal excursion areas (x-axis lists the receiving farms; c) overlaps among tidal excursion areas.

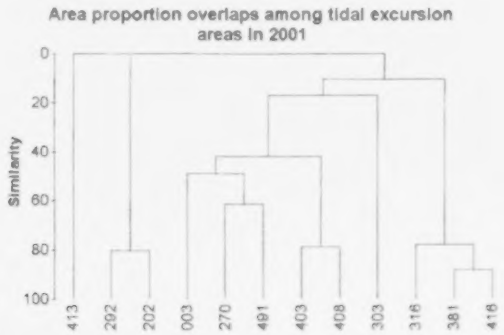

Fig. 24. Cluster anaiysis using Bray-Curtis similarity coefficients calculated on the areal extent of overlaps among model-derived tidal excursion areas, for finfish farms in the southern Grand Manan Island area in 2001. The coefficients were calculated on the areal proportion of the originating farm's tidal excursion area which overlapped the tidal excursion areas of farms operating in the area.

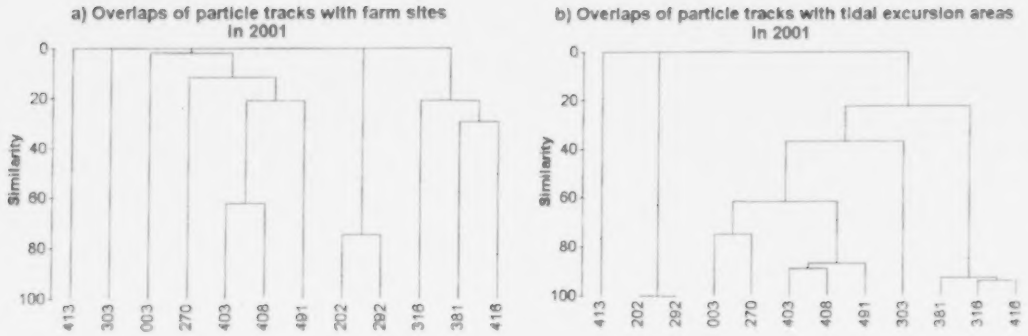

Fig. 25. Cluster analyses using Bray-Curtis similarity coefficients calculated on the number of model-derived particle tracks released from finfish farm sites in the southern Grand Manan Island area in 2001, which overlap with: a) farm sites; b) tidal excursion areas.

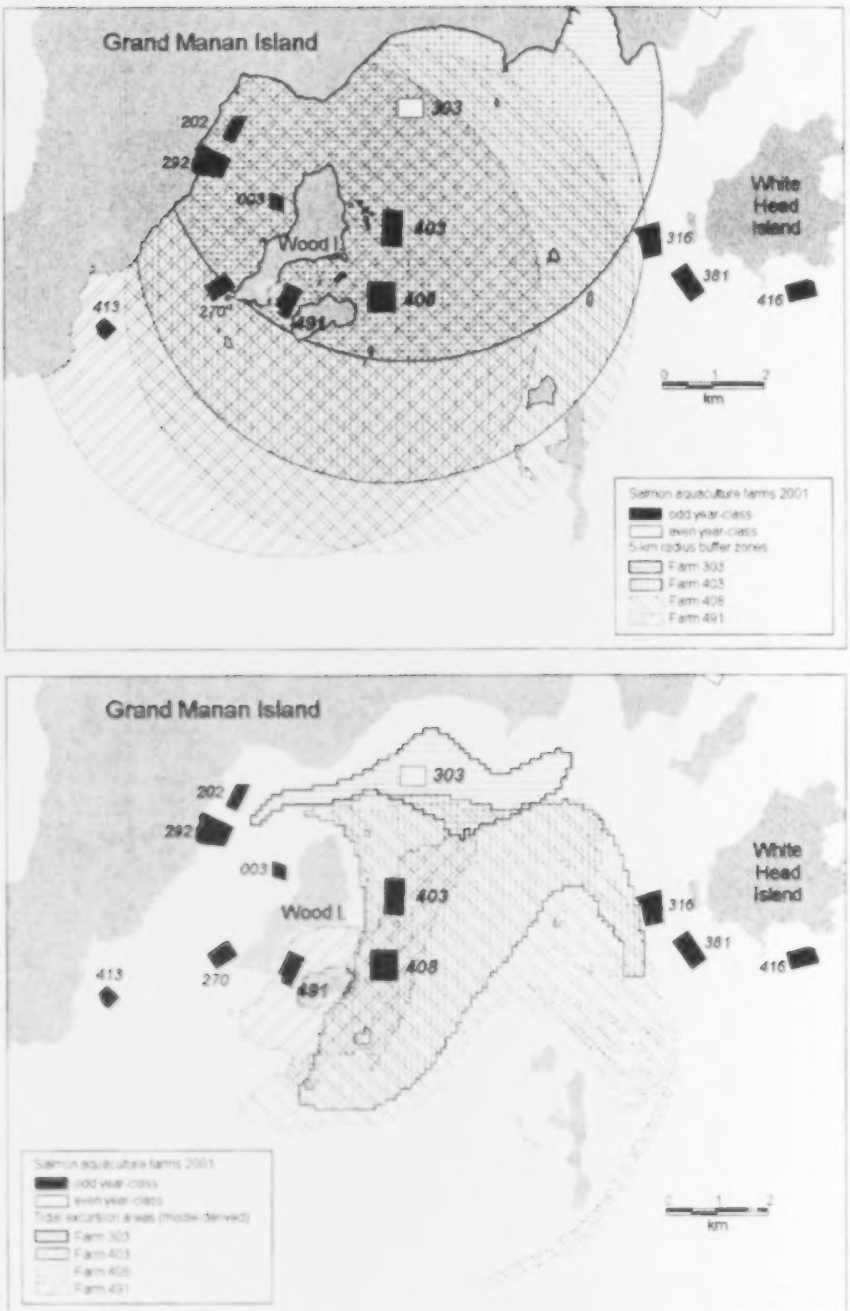

Fig. 26. Water exchange areas of even year-class farm 303 and odd year-class farms 403, 408 and 491 in the Long Pond Bay area (Bay Management Area 21). Top: 5-km radius buffer zones. Bottom: model-derived tidal excursion areas.

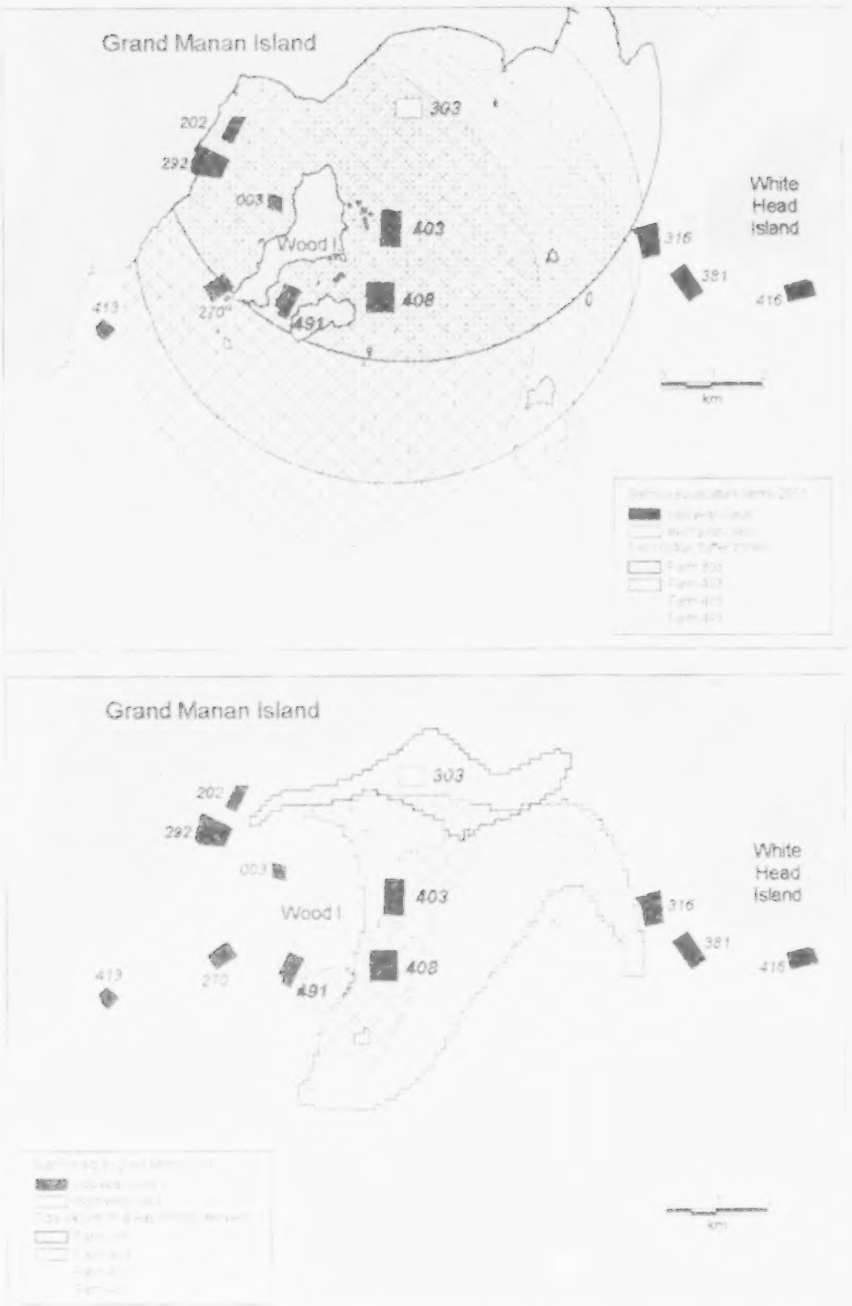

Fig. 26. Water exchange areas of even year-class farm 303 and odd year-class farms 403, 408 and 491 in the Long Pond Bay area (Bay Management Area 21). Top: 5-km radius buffer zones. Bottom: model-derived tidal excursion areas.

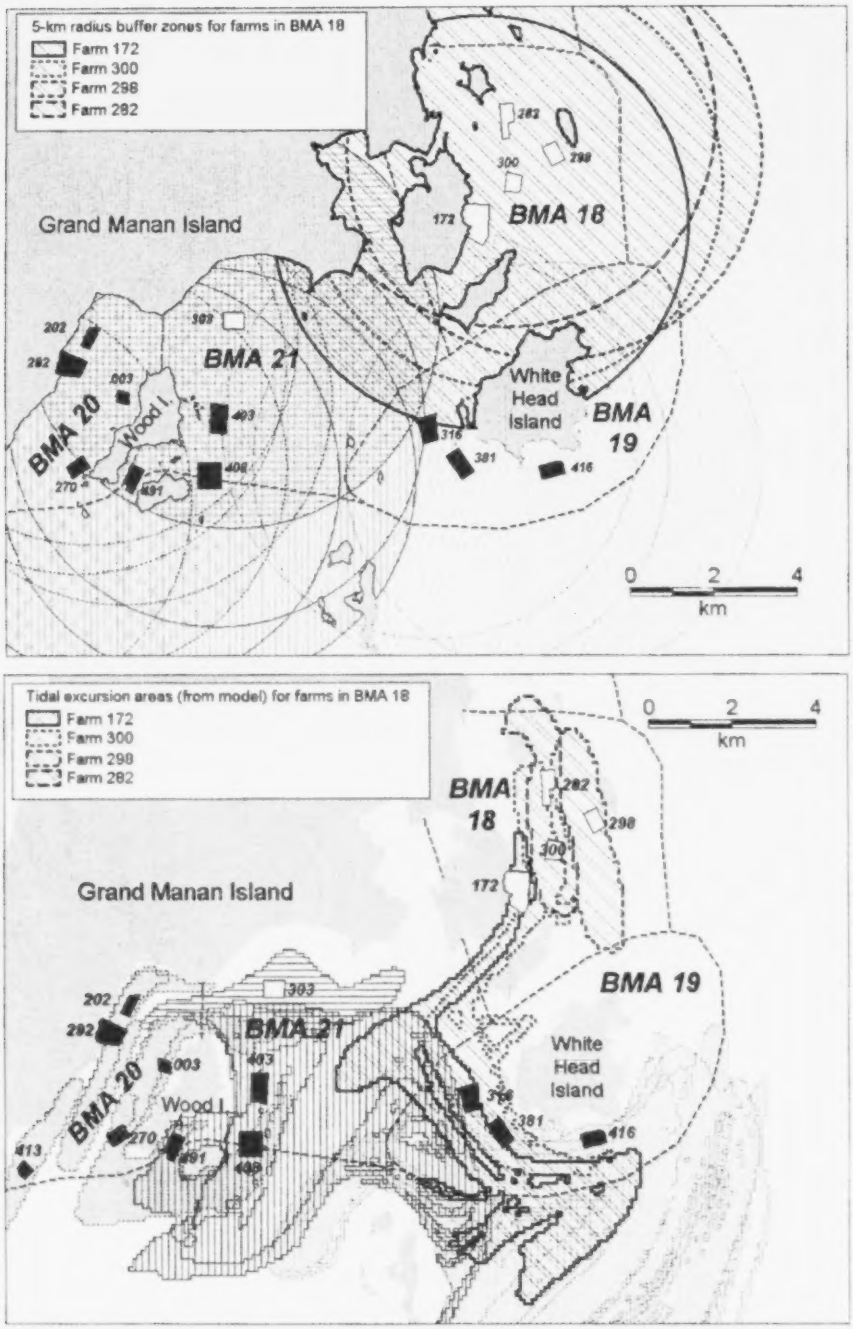

Fig. 27. Water exchange areas of farms in Bay Management Area (BMA) 18 in relation to farm sites and water exchange areas of farms in the southern Grand Manan Island area (BMAs 19-21) in 2001. Top: 5-km radius buffer zones. Bottom: model-derived tidal excursion areas. See also the legends for Figs. 9 and 21.

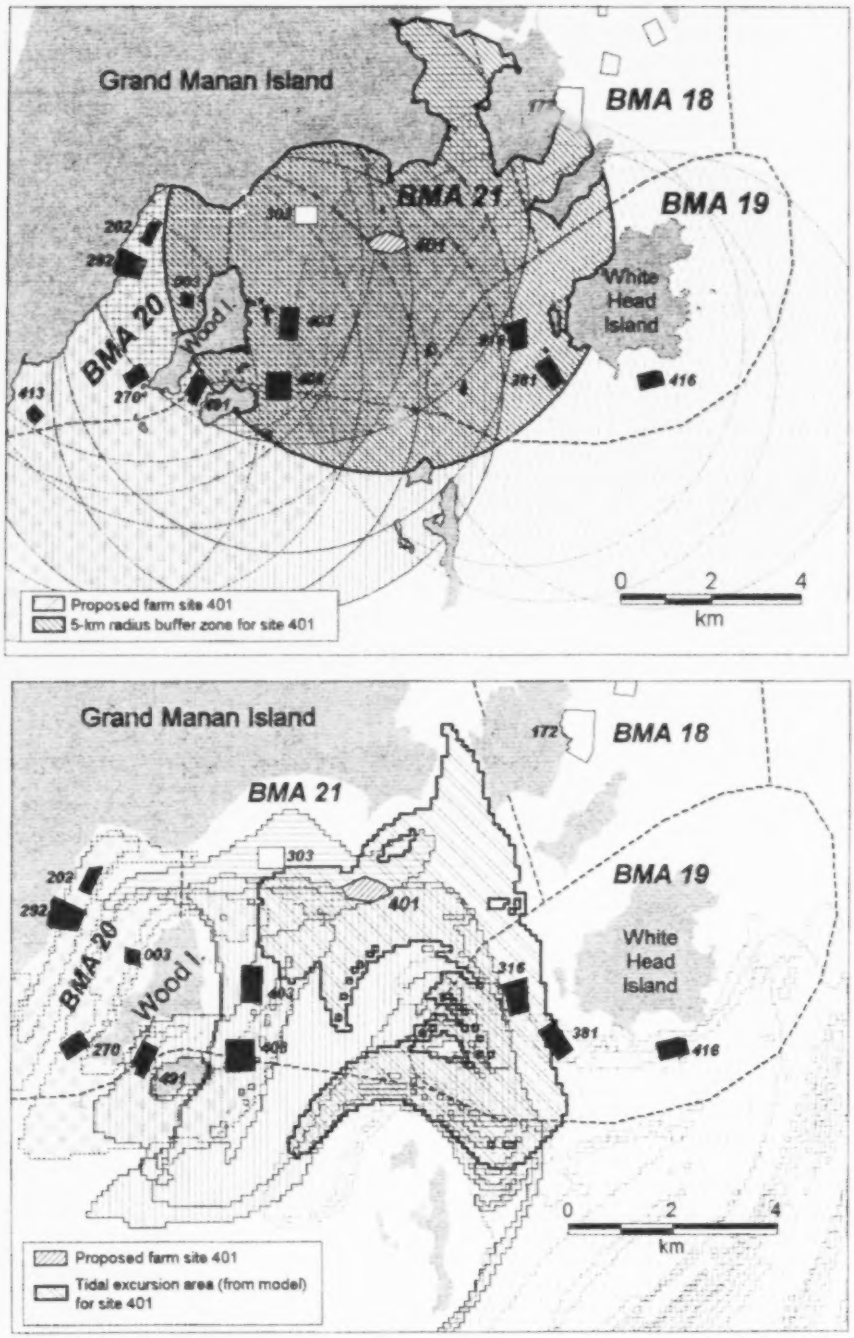

Fig. 28. Water exchange area of proposed farm site 401 in eastern Long Pond Bay (BMA 21), in relation to water exchange areas of licensed farms in 2001. Top: 5-km radius buffer zones. Bottom: model-derived tidal excursion areas. See also the legends for Figs. 9 and 21.

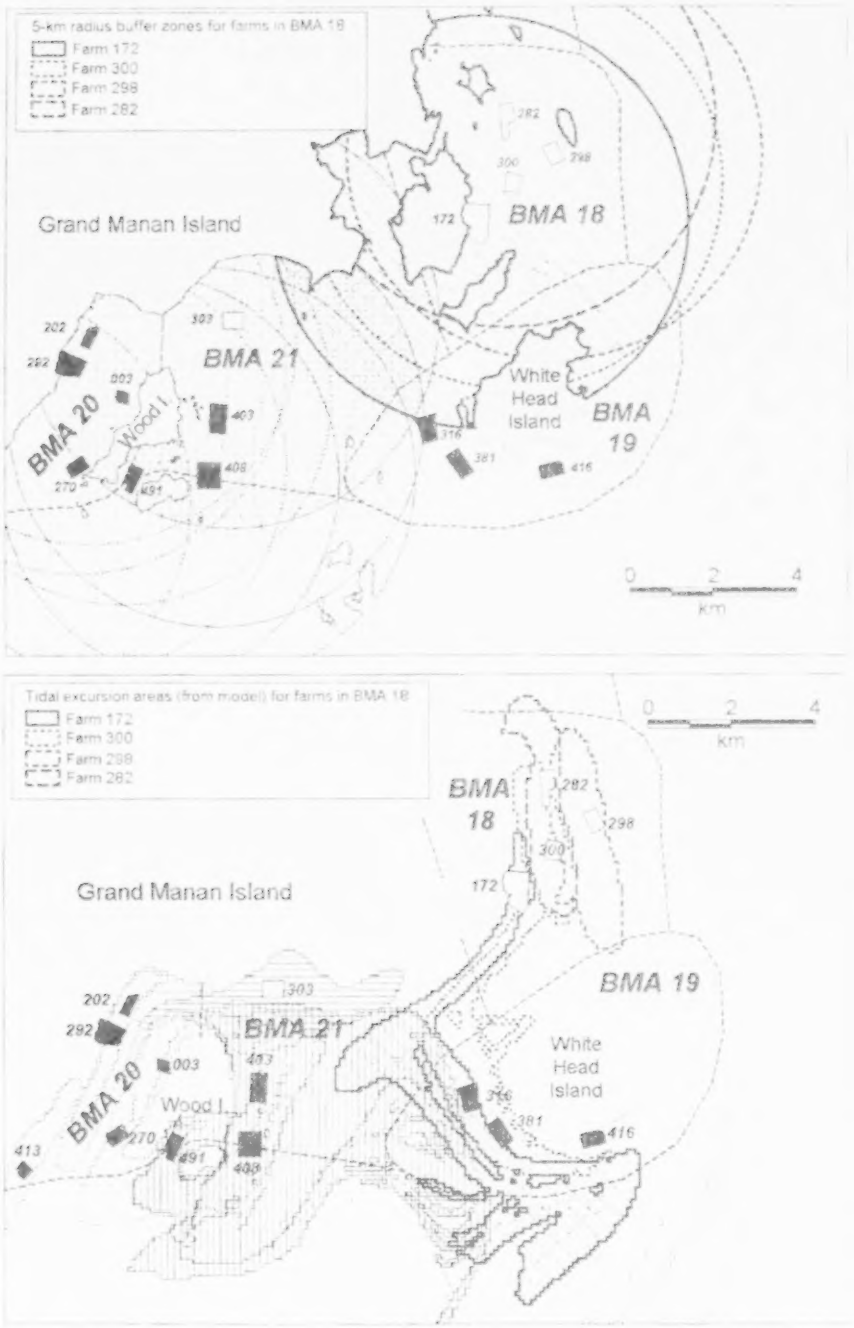

Fig. 27. Water exchange areas of farms in Bay Management Area (BMA) 18 in relation to farm sites and water exchange areas of farms in the southern Grand Manan Island area (BMAs 19-21) in 2001. Top: 5-km radius buffer zones. Bottom: model-derived tidal excursion areas. See also the legends for Figs. 9 and 21.

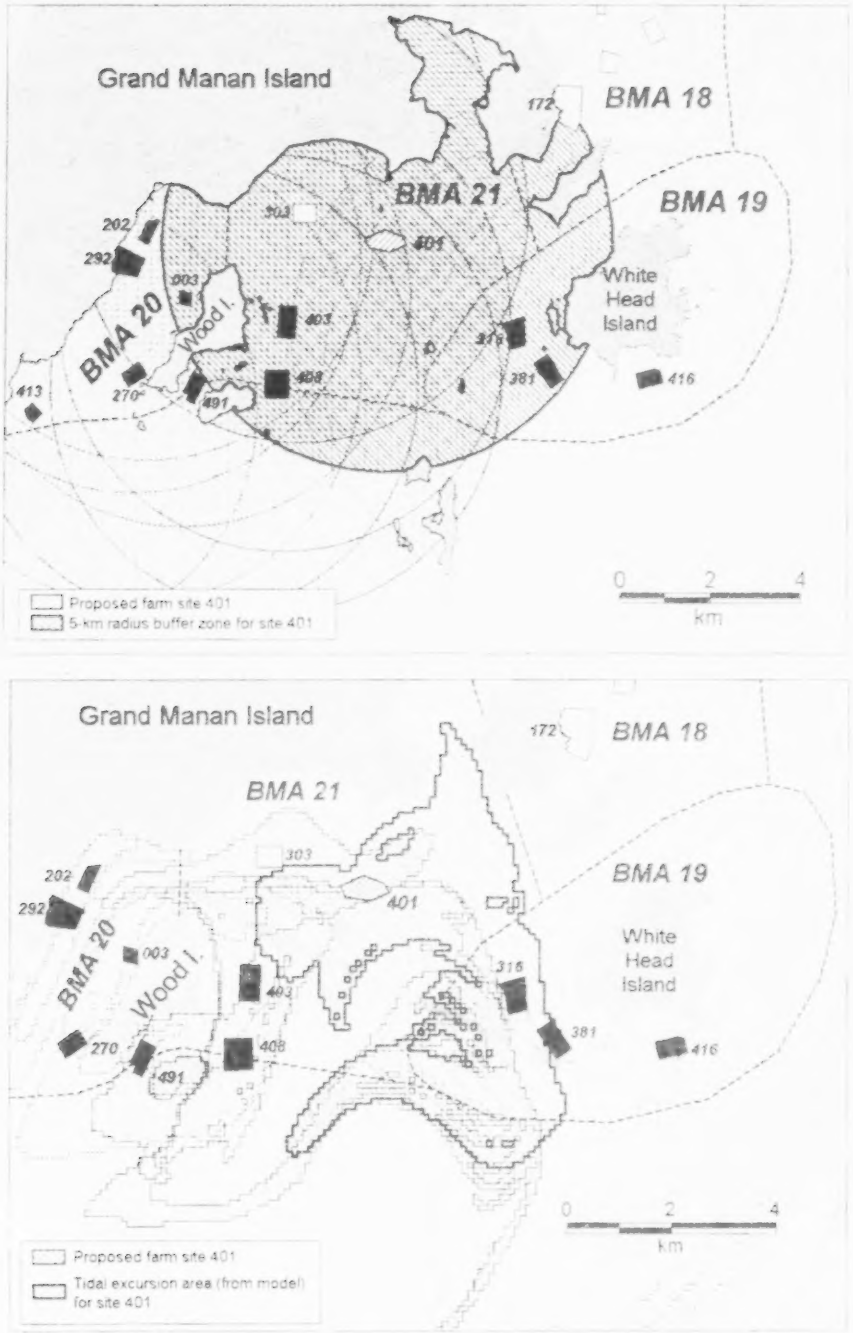

Fig. 28. Water exchange area of proposed farm site 401 in eastern Long Pond Bay (BMA 21), in relation to water exchange areas of licensed farms in 2001. Top: 5-km radius buffer zones. Bottom: model-derived tidal excursion areas. See also the legends for Figs. 9 and 21.

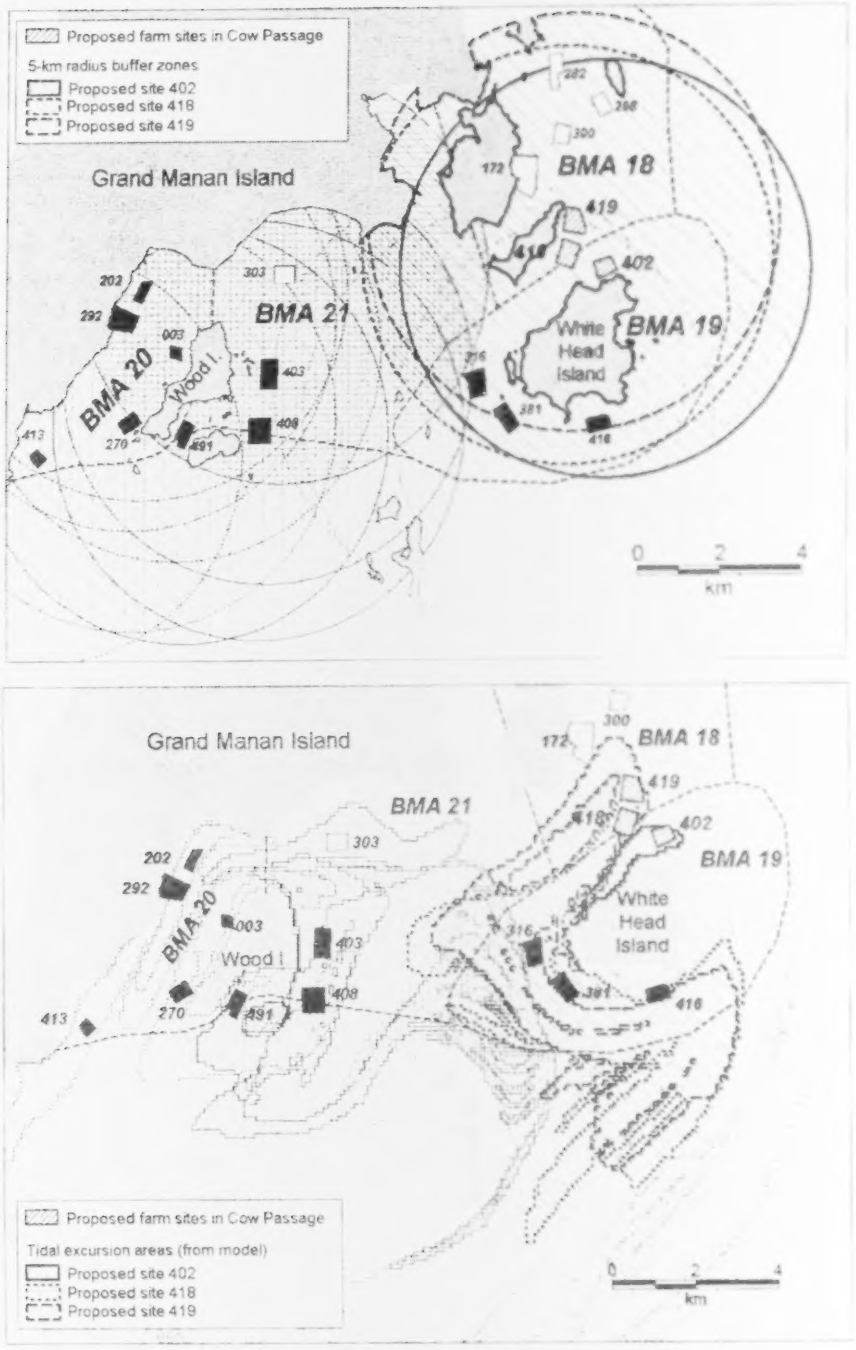

Fig. 29. Water exchange areas of proposed farms in Cow Passage, in relation to water exchange excursion areas of licensed farms in 2001. Top: 5-km radius buffer zones. Bottom: model-derived tidal excursion areas. See also the legends for Figs. 9 and 21.

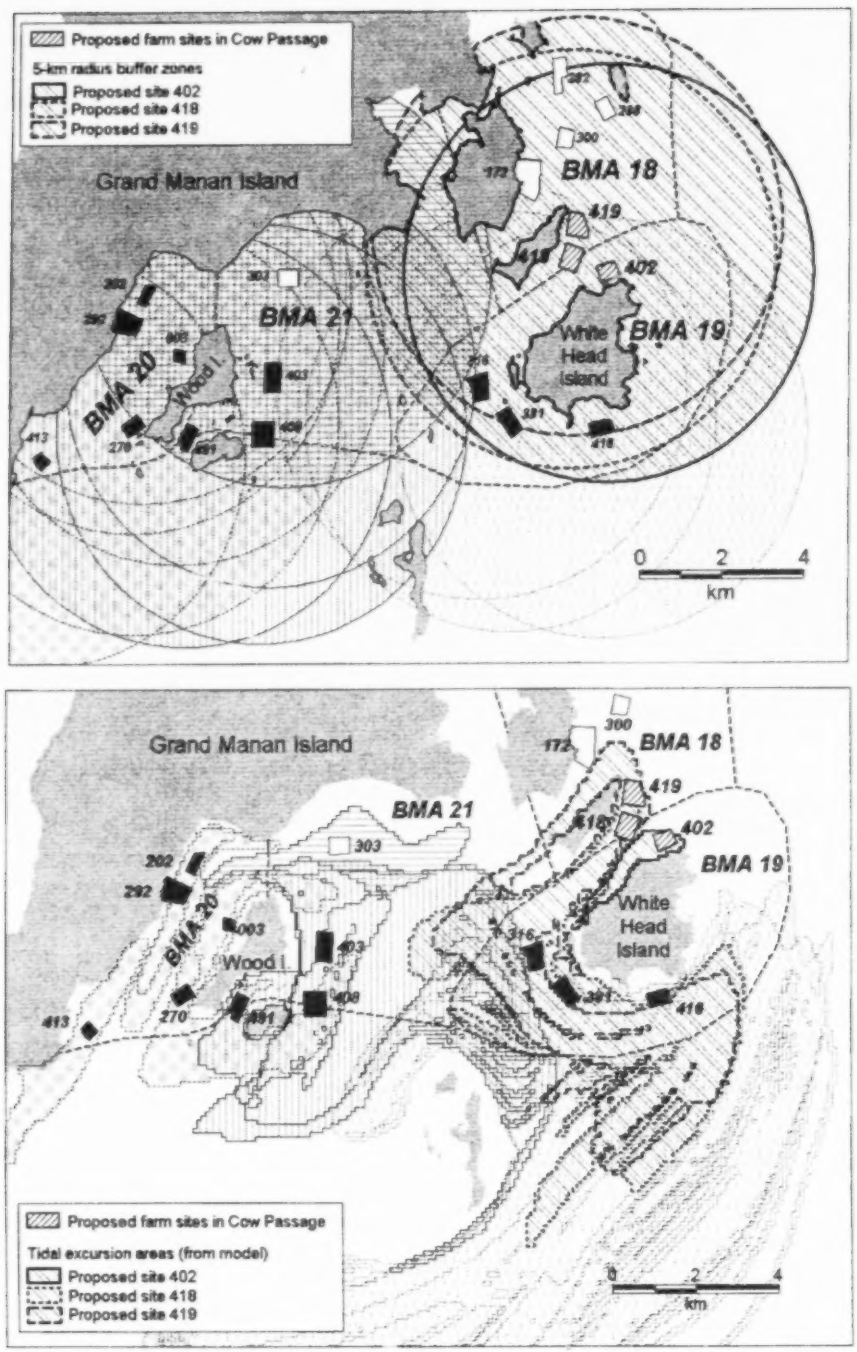

Fig. 29. Water exchange areas of proposed farms in Cow Passage, in relation to water exchange excursion areas of licensed farms in 2001. Top: 5-km radius buffer zones. Bottom: model-derived tidal excursion areas. See also the legends for Figs. 9 and 21.